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THE ALFALFA WEEVIL

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It has been our purpose to assemble the most important facts as direct quotations or to give the substance of them together with the references to the different authorities who have studied this insect in various parts of the world, so that there can be no mistakes in our attempted interpretation of the meaning of the authors. Naturally there are many statements which appear to be contradictory, but in nearly every such case the facts show that the apparent discrepancies are due to differences in climate, agricultural practices, the methods employed by the investigators, or some other factor.

SYSTEMATIC POSITION

According to the best authorities at this time the correct scientific name of the alfalfa weevil is *Phytonomus variabilis* (Herbst),[4] by which name, or as *Hypera variabilis* (Herbst), it has been known in Europe for a number of years (Joy, 1932).[5] In North America the names *Phytonomus posticus* (Gyllenhal) (Titus, 1911) and *Hypera postica* (Gyllenhal) (Essig, 1931) have been used up to this date.

The insect was first referred to in literature as *Curculio haemorrhoidalis* by Herbst in 1784 (Herbst, 1784), who subsequently described it as a new species, *Curculio variabilis* in 1795 (Herbst, 1795). Gyllenhal did not publish his description of *Phytonomus posticus* until 1810 (Gyllenhal, 1810), so this latter name must give way to the older one by Herbst.

Its wide natural distribution, climatic range, and variable coloration have resulted in much confusion in identifying the species and have given rise to many conflicting ideas concerning its exact systematic status. Some idea of the many names by which it has been known by various writers may be gained from the study made by Titus in 1911 (Titus, 1911). He lists 50 different aberrations, varieties, and species, and 6 different genera, together with 264 separate citations. Since then many additional references are to be found, chiefly in economic literature.

OLD-WORLD DISTRIBUTION

According to Titus (1911) the alfalfa weevil has a wide distribution in the Old World and occurs wherever alfalfa and other host plants are grown throughout Europe, excepting only the northernmost limits of Norway, Sweden, Finland, and Russia; in western central Asia, including southwestern Siberia, all of Turkestan, Persia, Arabia, Asia Minor,

[4] See Joy (1932).

[5] See "Selected Bibliography" for complete data on citations, which are referred to in the text by author and date of publication.

Fig. 1.—Map showing the approximate world distribution of the alfalfa weevil as known in 1932. (Outline map adapted from Goode's series of base maps and graphs No. 101 HC, by permission of the University of Chicago Press.)

and an area in Bengal, India; the north coast of Africa; and the Madeira and Canary Islands (fig. 1). It appears, however, to be most important as an economic pest in the more temperate sections of this vast area. A review of the economic literature dealing with this pest published since 1912 indicates that the insect has been observed in the following countries:

Bulgaria (Chorbadzhiev, 1931)
Denmark (Lind, Rostrup, and Kølpin Ravn, 1917; Ferdinandsen and Rostrup, 1921.
France (Picard, 1914*a*; Marchal and Foex, 1921; Grassé, 1929)
Germany (Lüstner, 1923; Molz and Müller, 1929)
Great Britain (Joy, 1932)
Italy (Martelli, 1911)
Morocco (De Lépiney and Mimeur, 1932)
Poland (Woroniecka, 1924; Krasucki, 1925)
Russian Socialist Soviet Republics:
  Kuban (Grossheim, 1913; Uvarov, 1917)
  Ukarine (Vassilier, 1913; Kolobova, 1929)
  Turkestan (Smirnov, 1913; Plotnikov, 1914; Dvornitchenko, 1917; Yakhontov, 1929, 1931; Kharin, 1930)
Spain (Spain, 1929; Benlloch, 1930)
Sweden (rarely) (Tullgren, 1917)
India: Pusa, Bengal (G. A. K. Marshall, 1913)

SPREAD IN THE UNITED STATES

Some idea of the extensiveness and the rapidity of the spread of this weevil in the United States (fig. 2) may be gained from the following tabulations:

1904.
Utah: The earliest record obtainable indicates that it was first noted on a farm on the east side of Salt Lake City in the spring of 1904 (Titus, 1910*a*).

1905.
Utah: Damage noticed in alfalfa fields several miles southeast of the 1904 infestations (Titus, 1910*a*).

1906.
Utah: Weevil found on northeast side of Murray (Titus, 1910*a*).

1907.
Utah: By the fall of 1907 the weevil had spread as far south as Big Cottonwood Creek, thus covering the alfalfa territory east of Salt Lake City and Murray (Titus, 1910*a*).

1908.
Utah: Infestation reached Sandy, West Jordan, Granger, Midvale, and Taylorsville (Titus, 1910*a*).

1909.
Utah: Almost 100 square miles of territory infested, comprising about 2,500 acres of alfalfa (Titus, 1909*b*); probably reached all parts of Salt Lake County, and as far north as Centerville in Davis County; also known to have been present in parts of Summit County, along the Weber River, for at least three years (Titus, 1910*a*).

1910.	
Utah:	New infested area July 1: Morgan, Weber, Tooele, Utah, and Wasatch counties and found at from 4,200 to 7,500 feet in altitude (Titus, 1910*a*, 1910*b*).
1911.	
Idaho, Utah, Wyoming	By September, 1911, the insect had extended its area of diffusion directly northward as far as Tremonton, Utah, east to Evanston, Almy, and Lyman, and northeast to Cokeville, Wyoming; Randolph, and Laketown, Utah; and Fish Haven, Idaho (Webster, 1912).
1912.	
Utah:	Parts of Box Elder, Cache, Rich, Sanpete, Millard, and Juab counties.
Wyoming:	Uinta County (Titus, 1913).
1913.	
Idaho:	In small numbers in Oneida, Franklin, and Bear Lake counties. Infestation extended over an area approximately 180 miles long by 90 miles wide (Parks, 1913).
1916.	
Idaho:	Cassia County.
Utah:	Carbon County.
Wyoming:	Lincoln and Sweetwater counties (Reeves, Miles, *et al.*, 1916).
1917.	
Colorado:	First infestation discovered near Paonia, in the upper part of the North Fork Valley, Delta County (Gillette and List, 1919).
1918.	
Colorado:	Gunnison County (List and Wakeland, 1919).
1919.	
Colorado:	Montrose County (Wakeland, 1920).
Oregon:	About the time the alfalfa weevil first appeared (Fulton, 1921).
1920.	
Nevada:	Weevil first discovered outside of Reno, Washoe County, in June (Nevada Agricultural Experiment Station, 1921).
1921.	
Idaho:	Infestation increased from 15 to 21 counties (Idaho Agricultural Experiment Station, 1921); Gooding County (Wakeland and Whelan, 1922*b*).
	Fremont County (Montana Agricultural Experiment Station, 1921).
Nevada:	Weevils present in all alfalfa fields lying north of the Truckee River from a point about 2 miles northwest of Reno to a point 5 miles east of the city (Nevada Agricultural Experiment Station, 1921). White Pine County (Creel, 1922; Snow, 1925).
1922.	
Idaho:	Just established in Canyon County (Wakeland and Whelan, 1922*a*).
Nevada:	Lovelock, Pershing County (Snow, 1925; Creel, 1922).
	Washoe County (Creel, 1922).
Oregon:	"Besides Malheur County, which was the only one infested last year, Baker County has been added as the weevil was found at Durkee, Oregon" (Wakeland and Whelan, 1922*b*).

Fig. 2.—Map of the United States showing the distribution of the alfalfa weevil, by states and counties, in 1932. (Outline map from the United States Department of Agriculture.)

1923.

California: Just across the boundary near Verdi, Nevada, July 6 (California State Department of Agriculture, 1923); found in Sierra County just across the Nevada boundary (Snow, 1925).

Fig. 3.—Approximate areas infested by the alfalfa weevil in 1932.

1924.

Nevada: At Fernley and Hazen, on the Swingle Bench, and at Dayton (Snow. 1925).

1925.

California: Plumas and Lassen counties (Urbahns, 1925).

Wyoming: Fremont, Natrona, and Converse counties. "This is the first known infestation of this insect on the eastern slope of the Rocky Mountains, and places this pest at the back door of the Mississippi Valley. It is not doing damage here yet" (Corkins, 1925).

.1926.

Colorado: Weevil discovered for the first time in portions of Rio Blanco, Routt, and Ouray counties; probably extension of the infested area in southwest Wyoming (Gillette, 1927); Moffat County (Reeves 1927*a*).

Fig. 4.—Distribution of alfalfa culture in 1930. (From Bul. 521.)

Idaho: Ada, Bannock, Bingham, Blaine, Bonneville, Butte, Camas, Jefferson, Jerome, Lincoln, Madison, Minidoka, Owyhee, Payette, Power, Twin Falls, Washington, Caribou, Clark, Custer, Elmore, and Gem counties (Reeves, 1927*a*).

Nevada: Weevil found in Mineral and Lyon counties for first time (Fleury, 1926); Churchill, Pershing, Storey, and Washoe counties (Reeves, 1927*a*).

Oregon: Union County added to list (Reeves, 1927*a*).
Utah: Beaver, Duchesne, Emery, Iron, Piute, Sevier, Uintah, and Washington counties (Reeves, 1927*a*).
Wyoming: Goshen and Carbon counties, near the Nebraska state line (Hyslop, 1926); Converse, Fremont, Laramie, and Natrona counties (Reeves, 1927*a*).

1927.
Nevada: Douglas County; a new infestation (Reeves, 1927*c*).
Wyoming: Niobrara County, a new infestation (Reeves, 1927*c*).
The alfalfa weevil has advanced from about 40 miles west of the Nebraska-Wyoming line to about 8 miles west of that line (Swenk, 1927).

1928.
Colorado: Discovered in Mesa and Garfield counties (Reeves, 1928).
Idaho: Discovered in Adams and Boise counties (Reeves, 1928).
Nevada: A recent find in Lincoln, Humboldt, and Elko counties (Reeves, 1928).
Nebraska: Record based on finding of a single larva; Scott's Bluff County was erroneously cited for Sioux County (United States Department of Agriculture Bureau of Entomology, 1929; Reeves, 1928).
Utah: Garfield County; a recent discovery (Reeves, 1928).

1929.
California: Alpine County, a new area; weevil spreading slowly in Lassen County east of the Sierra Nevada (Fleury, 1932*a*, p. 56).
Oregon: Jackson County a new infestation; no weevil noted so far that year in Union County (Cole, 1932, p. 60); found in Medford, Jackson County, in western Oregon (United States Department of Agriculture Bureau of Entomology, 1929).
Utah: Grand County, previously thought to be uninfested (F. E. Stephens, 1932; United States Department of Agriculture Bureau of Entomology, 1929).

1930.
Idaho: Ada, Bingham, Blaine, Bannock, Butte, Camas, Custer, Caribou, Clark, Elmore, Gem, Jefferson, Jerome, Lincoln, Madison, Minidoka, Payette, Power, Teton, Twin Falls, and Washington counties (Wakeland, 1930).
Wyoming: Southern two-thirds of the state under quarantine, but the pest had not reached the northern part of the state (F. E. Stephens, 1932, p. 118).

1932.
California: New infestations in Stanislaus, San Joaquin, Alameda, Santa Clara, and Contra Costa counties (Fleury, 1932*b*); a new very light infestation found near Coleville, Mono County (California State Department of Agriculture, 1932*a*).
Nevada: Ormsby and Lander counties added.[6]

1933.
California: Merced County.

[6] Reeves, G. I. Personal correspondence.

Summary of Distribution by States and Counties[7]

California:	Alameda, Alpine, Contra Costa, Lassen, Mono, Merced, Plumas, San Joaquin, Santa Clara, Sierra, Stanislaus.
Colorado:	Delta, Garfield, Gunnison, Mesa, Moffat, Ouray, Rio Blanco, Routt.
Idaho:	Ada, Adams, Bannock, Bear Lake, Bingham, Blaine, Boise, Bonneville, Butte, Camas, Canyon, Caribou, Cassia, Clark, Custer, Elmore, Franklin, Fremont, Gem, Gooding, Jefferson, Jerome, Lincoln, Madison, Minidoka, Oneida, Owyhee, Payette, Power, Teton, Twin Falls, Washington.
Nevada:	Churchill, Douglas, Elko, Humboldt, Lander, Lincoln, Lyon, Mineral, Ormsby, Pershing, Storey, Washoe, White Pine.
Oregon:	Baker, Harney, Jackson, Malheur, Union.
Utah:	Beaver, Box Elder, Cache, Carbon, Davis, Duchesne, Emery, Garfield, Grand, Iron, Juab, Millard, Morgan, Piute, Rich, Salt Lake, Sanpete, Sevier, Summit, Tooele, Uintah, Utah, Washington, Wasatch, Weber.
Wyoming:	Carbon, Converse, Fremont, Goshen, Laramie, Lincoln, Natrona, Niobrara, and Uinta.

DESCRIPTION AND LIFE HISTORY

ADULTS

The adult beetles (fig. 5) are described by Titus (1909*b*) as varying from $\frac{3}{20}$ in. long in the male to $\frac{1}{4}$ in. in the female. When freshly emerged they are brown with a distinct darker line extending centrally down the elytra. The head and pronotum are finely and closely pubescent with short gray hair, that on the head sometimes extending quite to the tip of the beak. The prothorax is slightly longer than wide, narrower in front than behind, widest in the middle, rounded on the sides and densely, finely punctured. There are two longitudinal stripes of fine brown scales, separated in the middle by a narrow gray line; the sides of the prothorax are covered with dense gray hairs. Elytra or wing covers are one-third wider than the prothorax, oval, but with sides nearly parallel, humeri rounded; the striae are distinctly punctured. The elytra have rows of fine gray setae alternating with hair-like scales, each being deeply cleft so that it appears as two hairs; and some fine darker hairs are present in such a manner as to present small spots of black. Antennae have the first funicle joint much longer than the second; last joint of the funicle is separated from club. Legs are dark brown with numerous gray hairs on the femora and tibiae; tarsi more sparsely pubescent. Antennae are slightly pubescent. The males are slightly narrower than the females.

[7] Some of these counties are only partially infested by the alfalfa weevil.

In the fields the two sexes are about equally divided as to numbers (Reeves, 1927*b*).

The brown color of the young beetles usually becomes darker as time passes, due to the rubbing-off or shedding of the scales and the darkening of the cuticula (Snow, 1928). Old adults sometimes become almost black, and this darker color helps to distinguish them from the new generation in late spring and summer. According to Snow (1928) the

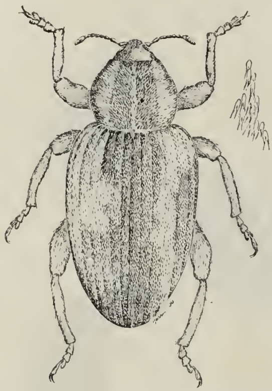

Fig. 5.—The alfalfa weevil, *Phytonomus variabilis* (Herbst). Adult and enlargement of scales which cover the body. (From *A History of Entomology,* Macmillan Co. Reproduced by permission of the copyright owners.)

period in which the two generations overlap is from May to October, and he calls attention to the fact that the difference in color "is not always marked enough to be a reliable means of separation. The change in color from light brown to dark brown does not all take place during the winter, as reported in early studies of the weevil, but chiefly later on near the beginning of summer; and even in the late summer old beetles are occasionally found with the scales not entirely removed and the color not distinctly dark."

According to Titus (1910*b*) the length of life of the adult cannot be definitely stated, but weevils were kept from the time they emerged in May for eighteen months. But according to the accumulated data the life of the adult is from ten to fourteen months, and in general the beetles which survive the winter die off rather rapidly after the egg-laying period is completed the following spring.

In the early spring after the hibernating adults become active they may do considerable damage to the alfalfa, which is just starting to

grow, by feeding on the young shoots. In some fields examined Titus (1910*a*) reported that over 30 per cent of the spring growth had been killed back by feeding punctures; the severity of the results was due to the fact that the plants were so small at the time injury was done that there was not room enough left for the sap to pass up the stems to maintain the growth. Other investigators also report the adults as feeding

Fig. 6.—The clover leaf weevil, *Phytonomus punctatus* (Fabr.) (*Hypera punctata*), a common insect in alfalfa fields often confused with the alfalfa weevil. (From *Insects of Western North America,* Macmillan Co. Reproduced by permission of the copyright owners.)

rather freely for several weeks in early spring when the plants are small, and under such conditions they often do considerable damage.

Wakeland (1924) cites instances where newly emerged adults, as well as larvae, have retarded development of the second crop and also observes that they have been known to kill young stands of alfalfa by migrating from a recently cut field to an adjoining new stand and eating the plants before the roots became established. Titus (1910*a*) has also pointed out that where large numbers of adults occur in a field, considerable damage may be done to the second crop, and sometimes even to an early third crop of alfalfa. The spring feeding habits of the weevils consist in making punctures in the stalks, whereas in the later feedings, on the second and third crops, they rasp the epidermis from the stalk and slit the leaves into ribbons (Titus, 1910*b*).

The majority of the weevils feed on the leaves at night from 9 p.m. to 1 a.m., and many of them are partly concealed on the plant and again feed about daylight. After this they go down to the ground and many stay hidden until dark, while others feed some during the day on the stalks and the leaves of the plant. Reeves, Miles, *et al.* (1916) report that the weevils stay close to the ground during early spring and late fall; and that at the time of cutting the second crop the fields are full of weevils of the new generation. Hay of the second crop contains many more adults than that of the first or third crop. The adults are more active by night than by day during the summer, and this condition continues until the cool weather of September sets in. As fall approaches they frequent the plants less and less.

When feeding on the plants they readily drop to the ground upon the slightest disturbance, and because of this habit they are not readily seen in the fields. In the San Francisco Bay area of California opportunities for observing the habits of the adults have been few. However, during the first half of June, 1932, on warm quiet days towards noon a fair number of the adults could be observed feeding on the terminal growth in fields which had the heaviest infestation. During the mornings on such days the weevils could be found at the base of the plant, and upon being disturbed, many at least would crawl away, rather than remain motionless as is so often reported. As yet no observations have been made in California as to the night activity of the adults, but an investigation on this point is planned. Although the adults feed throughout the year, the damage caused by them, when compared to that of the larvae, amounts to very little.

Titus (1910*a*) reports that there are repeated periods of mating, and that the males often accompany the females during oviposition; and Parks (1914) states that copulation continues all during the oviposition period. In our observations the beetles have been noted to mate throughout the spring, summer, and fall. Whether these are of the old or new generations, or both, is not known. Dark-colored adults have been observed mating with light-colored individuals, which might indicate that there is mating between the old and new generation, but the difference in color is not always marked enough to be a reliable means of separating the newly emerged from the hibernating forms. However, Titus (1910*b*) reports that copulation has been noticed between newly emerged males and females of the previous year in early July, and that the mating of overwintering forms appears to be continuous from spring to fall.

According to Reeves (1927*b*), the alfalfa weevil has no definite period of hibernation. The adults are quiet when they are cold and active when

TABLE 1

EGG-LAYING HABITS OF THE ALFALFA WEEVIL

Investigator	Area	Where eggs are first deposited in the early spring	Where eggs are deposited later in the year	Period when eggs are most numerous
Titus (1909*b*)	Utah	....	On the plants and most of those found near the growing tips	....
Titus (1910*a*)	Utah	On stems, or through the base of the leaves into the young growing buds or even directly on or in the terminal buds	Majority of eggs laid in stems	April-June
Titus (1910*b*)	Utah	Single on the plant, in the buds, axils of the leaves, on the stalk, or beneath the leaf sheath	In the stalks	....
Webster (1912)	Utah	A few on outside of plants. Occurs mostly when growings stems of alfalfa are too small or not sufficiently numerous	In the stalks	May-June
Parks (1913)	Idaho	Placed in the stems	Placed in the stems	April-June
Titus (1913)	Utah	On stems and buds, even dropped on the ground or around the plants	Placed in the stems	April-June
Parks (1914)	Idaho	In dead stems of the previous season's growth which are lying on the ground. Later a few placed in green weeds and grass stems	Placed in the stems	May
Reeves, Miles, *et al.* (1916)	Utah and other states	Dry and dead stems on the ground	Placed in the stems; a few eggs on outside of plants, and more in weeds and grasses	May-June
Reeves (1917)	Utah	Dead stems which litter the ground weeks before spring growth of plants starts	Placed in the stems	May
List and Wakeland (1919)	Colorado	In dead grass stems (not alfalfa stems)	Placed in the stems	....
Reeves, Chamberlin, *et al.* (1920)	Utah and other states	Soft dead stems on the ground	Placed in the stems	May
Wakeland (1924)	Idaho	Dead grass stems scattered on the ground	Later in the season many are laid in green alfalfa stems; apparently a greater proportion is deposited in dry stems throughout the season in lower, warmer localities than in higher, cooler ones	May
Snow (1925)	Nevada	In green stems and in the dry grass and alfalfa stems on the ground	....	May
Reeves (1927*b*)	Utah and other states	Dry stems on the ground	Placed in stems	April-May
Sweetman (1929)	Wyoming	....	Most eggs (about 90%) deposited in the stems near the crown; stems in the field showed that 93% of the egg clusters were placed in green stems, 6% in dead standing stems, and 1% in dead fallen stems	May

they are warm. When cold weather approaches the adult weevils creep down close to the ground and into crevices and spend the winter there. Ditch banks and other uncultivated places, which are strewn with litter of dead vegetation, often harbor many of them, but their numbers in these situations are insignificant compared with those which remain in the fields. List and Wakeland (1919) also noted that on warm days in winter the beetles were found active in fields where the snow had melted. Titus (1910*a*) reported the significant fact that from 75 to 80 per cent of the weevils going into hibernation survived the winters of Utah.

EGG-LAYING HABITS

According to most investigators egg-laying begins as soon as warm weather sets in, early in the spring. Usually the first eggs are laid in dead stems, but as the season progresses they are laid mostly in the green alfalfa stems. Generally at first only a few eggs are laid here and there but when the continued warm weather starts egg-laying begins in earnest. To review all that the different investigators have to report on egg-laying would take a considerable amount of space, and as most workers are in fair agreement as to the egg-laying habits, the data have been summarized in table 1.

EGGS

The eggs (fig. 7) of the alfalfa weevil are small, oval, and yellow or orange-yellow in color. To the unaided eye they appear smooth and shiny, but under a microscope the surface of the egg appears very slightly roughened and sculptured. However, a few days after incubation the color of the egg becomes dingy, and towards the latter part of the incubation period the head of the larva shows through the shell as a black spot.

The most probable explanation for the laying of the early eggs in dead stems is the lack of suitable green stems for egg deposition. That female beetles show preference for a certain type of stem is indicated by the investigations of Sweetman (1929), who says: "Apparently the ease with which the stems can be penetrated together with ample space for the eggs within the hollow portions of the stems are important factors influencing the location of places for oviposition. This condition seems to be found most often in the medium-sized stems. Also, the females may find the stems of this size easier to cling to while ovipositing than those of larger or smaller diameter." In this connection he also found that medium-sized stems were used twice as often as the large stems and

three times as often as the small ones, and that a great many of the small stems had no hollow interiors. Webster (1912) reports that tall stems which have made a rapid growth are the ones chosen by the insect for egg-laying. He adds that shorter woodier stems seem seldom to be selected for this purpose.

The adult weevil makes two kinds of punctures, one for feeding, and the other for egg-laying. Feeding holes are easily recognized by their

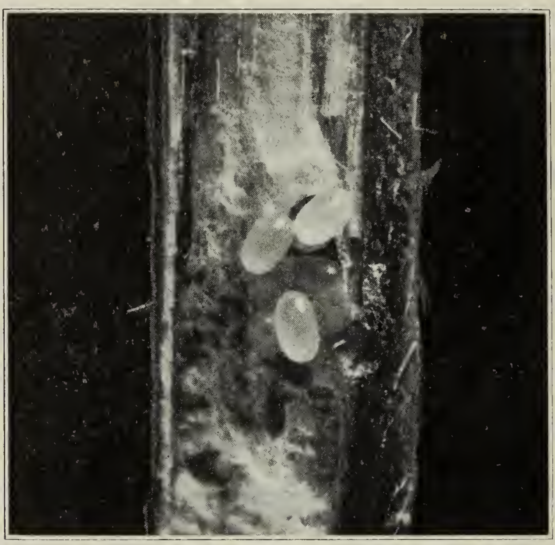

Fig. 7.—Eggs of the alfalfa weevil deposited in the stem of an alfalfa plant. A portion of the stem has been removed to expose the eggs which were inserted through a small, obscure puncture. Greatly enlarged. (Photo by Matthews.)

irregularity in outline, while egg punctures are generally very much smaller, circular, and smooth. The female makes the egg punctures with her snout, and the process according to Titus (1910*b*) consists in making but one cut with the beak while standing lengthwise of the stem, head downward, the beak being inserted at an angle slightly toward the base of the stalk and given a steady pull up and in, thus making an elongated slit inside the stem, both below and above the puncture. The beak was then withdrawn and the insect either turned around or walked forward and pushed her ovipositor into the puncture. Thirty seconds to 2 minutes are required to lay an egg, and according to Titus (1910*a*) the ovipositor is apparently withdrawn after each egg is laid, but Webster (1912) reports that a number of eggs are laid before the ovipositor is removed from the cavity. Parks (1914) noted that 1 to 4 minutes

elapse between the passage of each through the ovipositor. When a large number of eggs are laid the last one often fills the entrance to the puncture. If this does not occur the female is likely to seal the opening with a secretion. These sealed punctures are easily seen as small dark spots, when alfalfa stems are closely examined. The reason for sealing the punctures is probably to protect the eggs from other organisms, or from drying. That drying is an important consideration is suggested by Sweetman (1932), whose work indicates that low humidities of 50 per cent or less for a few hours during the day are sufficient to kill many of the embryos and that the normal moisture content in the green stems where the eggs are usually laid is probably high enough so that the eggs ordinarily would not be exposed to such low humidities. In a more recent paper Sweetman and Wedemeyer (1933) report the favorable range of temperature for the hatching of the eggs to be between 68° and 86° F with relative humidities of 55 to 95 per cent. Temperatures of 89.6° to 93.2° F were unfavorable for hatching of the eggs, but the length of the incubation period was much shortened; higher temperatures destroyed the embryos.

In regard to incubation period, number of eggs per female, etc., considerable data have been obtained. A portion of this information has been tabulated in table 2. As would be expected there is much variation in the figures. Most of this can probably be accounted for by the different conditions under which the work was performed, and also by the fact that some of the figures are supposed to be only estimates. In the case of incubation period the large deviations might well be taken to denote what might be expected under different temperature conditions.

That the incubation period may be longer than that shown in the table is evident from the work of Reeves, Miles, *et al.* (1916) which showed that eggs laid in the fall did not hatch before the following spring. This same condition of eggs passing through winter is also pointed out by Reeves (1927*b*) and Snow (1925), and even as early as 1912 Webster suspected that in Utah some eggs might survive the winter. Therefore, it is easily seen that where eggs pass through the winter in a living condition the incubation period is of necessity very long.

In this connection it should be stated that there is some evidence that eggs may be winter-killed in areas of low temperatures as in the Great Basin. Titus (1913) states that "eggs laid in the fall on the ground or in weeds and hollow stubble are apparently to a large extent infertile or injured by the weather so that they fail to hatch," and Parks (1914) has pointed out that eggs deposited in the autumn of 1911 in Idaho were killed by the low winter temperatures, and concludes that as far as

TABLE 2

INCUBATION OF THE EGGS OF THE ALFALFA WEEVIL

Investigator	Number of eggs per female	Incubation period, in days	Number of eggs per puncture		
			Range	Usual	Maximum
Titus (1910*a*)	200 to 300	In one lot of 1,139 eggs the incubation period varied from 7 to 16 days, averaging slightly over 10 days	1 to 28	Of 2,373 eggs the average per puncture was 6.29, and 16.61 eggs to a stalk	....
Titus (1910*b*)	....	7 to 16 days, averaging about 10 days	....	....	....
Webster (1912)	....	7 to 10 days About 10 days About 13 days	2 to over 30	10 about the average	Over 30
Titus (1913)	1 female may lay over 1,500 eggs; average 600 to 800	....	1 to 45	....	45
Parks (1913)	700 to 800; average number deposited by 16 females 726	8 to 15	....	6 to 14	....
Parks (1914)	Largest number deposited 1,184, average 726; with 11 females allowed to deposit eggs in a warm laboratory during winter and spring, the average number of eggs deposited was 913; one female laid 1,918	....	2 to 30	6 to 18	....
Hagan (1918)	600 to 800	....	....	....	40
List and Wakeland (1919)	....	Under laboratory conditions the average incubation period for the entire season was 14.69 days	1 to 30 or more	....	....
Reeves, Chamberlin, and Pack (1920)	....	Eggs develop slowly at first and faster as the temperature rises, until in May and June they hatch within 2 weeks after they are laid	....	....	....
Wakeland (1924)	....	Average length of the egg stage is about 14 days	....	....	....
Snow (1925)	....	10 days to 2 weeks	1 to 30 or more	....	....
Reeves (1927*b*)	....	....	4 to 16	About 10	....
Sweetman (1929)	....	Average incubation period 2-inch level was 18.6; average incubation period 2½-foot level was 19.8	3 to 12; in solid stems 3 to 6	6 to 9	45

known, either all the eggs deposited in the autumn perish before hatching or the larvae are killed by the winter. It should be noted that the investigations of Titus and Parks were carried on prior to those of Reeves and Snow, and that the conflicting reports might easily be accounted for by differences in climatic conditions under which the investigations may have been conducted.

LARVAE

The larvae (fig. 8) of the alfalfa weevil do by far the most damage to crops. On hatching, the young larva is about $\frac{1}{32}$ inch long, light yellowish green or almost tan in color except for the black head. After the first molt the color changes to a light green. The mature larva is about $\frac{1}{4}$ inch long, with a rather wide dorsal white stripe running down its back. This white or pale stripe is noticeable in the very young larvae and becomes more pronounced as the larva matures. Also on either side there is a very faint white line. The body is marked with many wrinkles which extend around the back and sides.

It is recorded by Webster (1912) that the newly hatched larvae are remarkably vigorous and that very young ones exhibit great energy as travelers. Their mode of progression is to reach forward and then, with a slight hump, to bring up the rear part of the body. The head is at once thrust forward again. About one move is made per second, and three propulsions will carry the body forward 1 mm. When in doubt as to the direction to be taken, the larva elevates the head and swings it from side to side until some decision is reached, when the journey is resumed. The larvae are positively phototropic.

Titus (1910*a*) states that the larva in emerging from the egg does not cut an opening in making its exit from the shell, but, by muscular contractions, rolling and twisting inside the shell, obtains sufficient pressure to burst through the thin membrane.

Soon after hatching the larvae start feeding in the interior of the stalk, and sometimes remain there 3 or 4 days, before working their way up the outside of the stem to conceal themselves in the leaf buds, usually at the top of the plant. Here they generally feed through the remainder of the first stage, and sometimes during the second larval period. That the early feeding of the larvae is confined to the leaf buds or terminal growth is an observation generally agreed on by most investigators (Webster, 1912; Reeves, Miles, *et al.,* 1916; Hagan, 1918; List and Wakeland, 1919; and Sweetman, 1932). While feeding in this position the larvae are most often concealed and not easily seen. Webster (1912) points out that the selection of the terminal growth may be in part due

to the shelter offered as well as to the more tender and succulent nature of the growth, and Sweetman (1929) suggests also that the larvae seclude themselves in the growing tips and axils of plants when the alfalfa is disturbed by wind and rain.

Fig. 8.—Mature larvae of the alfalfa weevil, left, and the clover leaf weevil, right. The latter are much larger and have pink lines bordering the white dorsal stripe. Immature forms of the clover leaf weevil also have the posterior part of the body pinkish. (Photo by Matthews.)

Fig. 9.—Alfalfa plants showing the injury done by the larvae of the alfalfa weevil where an average population occurs in slightly neglected fields. Such injury is seldom noted by the grower unless his attention has been called to it. (Photo by Matthews.)

Parks (1913) records that many of the older larvae go into the crown of the plant during the day and come out to feed at night. From 6:00 P.M. to 1:00 A.M. both the larvae and beetles are found feeding in greatest

numbers, although many are found feeding all through the day. As the larvae become older they start feeding on other parts of the plants.

Reeves, Miles, *et al.* (1916) state that in the absence of control measures the larvae appear in large numbers about the end of May or earlier if the spring has been favorable, and eat the leaves, especially on the young shoots, so rapidly that the plants are unable to outgrow the injury. In general the period over which the larvae may do serious damage is from May to early in July, depending of course on location and weather conditions. The feeding increases steadily until after the height of the hatching season, but the plants are able to outgrow the injury until just before cutting time—when the larvae may become so numerous as to destroy the growing tips completely and thus stop the growth of the plants. This condition is usually reached one or two weeks before the crop is ready to be cut, and if no control measures are resorted to, serious injury results. After this period the appearance of the field changes rapidly; the leaves are consumed until nothing is left but woody fibers and the tops of the plants are as white as if they had been frost-bitten. The injury spreads downward, and before the normal cutting time, if the fields are allowed to stand, the whole plant is bare of leaves and the green covering has been stripped from the stems.

Titus (1909*b*) notes that where young larvae are forced to feed on the older leaves they only skeletonize the foliage. He further adds that this often gives the plants the appearance of having been frosted except that the color is whiter than after frost injury (fig. 10).

After the larvae have grown to be about two-thirds mature they are often easily seen on the plants, where they may be observed curled around a portion of a leaf, stem, or bud.

Wakeland's (1925) observations during four seasons showed that from the time when the number of young larvae in a field exceeds about 1,000 for each 100 strokes of the sweeping insect net until the time when they decrease to less than that number, the amount of feeding is great enough to cause serious damage.

If, at the time the first crop is harvested, there are numerous larvae in the fields, the second crop may be greatly delayed. Titus (1910*a*) calls attention to the fact that in Utah the larvae are nearly full-grown at the usual time of cutting the first crop, and that many of them crawl back to the stubble and prevent the second crop from starting for several weeks. Reeves, Miles, *et al.* (1916) also note that the larvae feeding upon the first crop gather upon the buds of the stubble, and although many have been killed by the exposure to the heat of the earth after cutting, there are still enough to prevent the growing of the second crop for a

time nearly equal to its usual period of growth. Snow (1925) adds that in Nevada where the first crop is cut early, while few of the larvae are full-grown, the second crop may be delayed 3 or 4 weeks. All investigators agree that the second crop is usually delayed until the majority of the larvae have reached maturity and pupated.

Fig. 10.—Alfalfa plants rather seriously damaged by the larvae of the alfalfa weevil. Such injury is caused by large populations of weevils in neglected fields and may result in considerable losses. Under these conditions the injured tops become dry and whitish and artificial control may be justifiable. (Photo by Matthews.)

Wakeland (1924) also points out that an infestation which would be considered of little importance in a hay field is often sufficient to render seed production unprofitable, for since the larvae feed in the newly developing tips almost entirely, they destroy blossom buds and thus prevent seed development.

In an infested area the enormous numbers of larvae and eggs that occur to the acre is indicated by Reeves (1917): The total number of larvae and eggs present in a measured area of a certain typical field in 1913 in Utah was equivalent to 8,240,000 per acre on May 5; to 15,650,000 on May 14; to 22,920,000 on May 21; and to 10,410,000 on May 31; and on June 5 the number shrank to 310,000 per acre, because the maturing of the larvae outran the deposition of eggs.

Table 3 summarizes a portion of the data on larval development and

gives the length of the larval period, number of molts, length of time between the individual molts, and length of pupal period.

According to Titus (1910*b*) the molting process of the larvae is about the same in all stages. He states:

> This casting-off of the skin is a rather slow process. The first evidence is the slight shortening of the larva, soon followed by the splitting of the head plate, beginning at the center of the inverted "y," the parts rolling back and then spreading a short distance down the back, rarely more than 2 segments, the larva working its way out through this opening. The cast skin soon dries and shrivels up, so that it is almost impossible to find it.

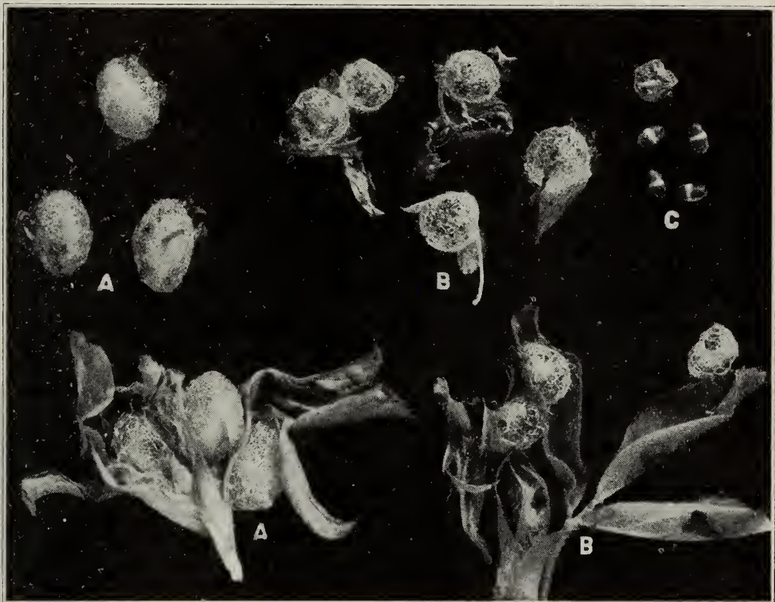

Fig. 11.—*A*, Cocoons of the clover leaf weevil; *B*, cocoons of the alfalfa weevil; *C*, cocoons of the alfalfa weevil parasite, *Bathyplectes curculionis* (Thoms.). The latter occur within the cocoons of both the weevils. Note the oblong shape of the larger cocoons of the clover leaf weevil and the more globular and smaller cocoons of the alfalfa weevil. These weevil cocoons often occur together usually about the bases of the alfalfa plants. (Photo by Matthews.)

PUPAE

Upon reaching maturity the larvae either crawl or drop to the ground, where they spin a delicate net-like cocoon (fig. 11) of white silken threads. The cocoon is roughly globular and is often partly enveloped by one or more leaves. It is lightly attached to the rubbish on the ground or to the stubble at the base of the plants. Titus (1910*a*) notes that it takes the larvae 10 to 20 hours to spin the cocoons; and from 36 to 72 hours after this they transform into the pupae. The newly formed pupa

is pale yellowish green changing to light brown as it approaches maturity. After transformation the adult weevil remains within the cocoon a few days before making its exit. It then cuts its way out of the cocoon, crawls up the stem, and begins to feed.

TABLE 3

LARVAL DEVELOPMENT OF THE ALFALFA WEEVIL

Authority	Length of larval period	Number of instars	Length of individual instars	Length of pupal stage
Titus (1909*b*)	32 to 40 days....	At least 4...........	Each lasts from 8 to 10 days.........................	10 to 14 days
Titus (1910*a*)	....	....	5 to 8, 12 to 20, 12 to 30....	6 to 14
Titus (1910*b*)	....	....	....	Averages about 8 days
Webster (1912)	....	....	5 to 8, 12 to 20, 12 to 30....	....
Titus (1913)	....	....	....	10 to 14 days
Parks (1913)	....	....	....	About 36 hours after spinning cocoon larva changes to pupa and the adult emerges about 10 days later (during July)
Reeves, Miles, *et al.* (1916)	....	3 to 4 depending on the season of the year in which the larval life is spent............	....	....
Hagan (1918)	....	....	....	Pupa requires about 10 days to become an adult insect
List, Wakeland (1919)	21.86 average for the season	3 times with a very small percentage undergoing a fourth............	....	Average length of pupal stage 15.82
Wakeland (1924)	About 3 weeks average............	....	....	....
Snow (1925)	5 to 6 weeks......	....	....	7 to 10 days
Sweetman (1932)	23 to 28 days....	....	....	10 to 11 days

While it is the general thing for the larvae to pupate close to the ground, Titus (1910*a*) remarks that when there is dead alfalfa such as that injured by frost, cocoons may be found 6 inches above the surface of the soil.

PARTIAL SECOND GENERATION

After the heavy egg-laying period in late spring a few eggs are deposited during the summer and into the fall. This immediately brings up the question whether any of these are laid by the new generation

of beetles. Titus (1909*b*) reports that larvae not half grown were collected on September 14. These he believed were probably belated larvae that had failed to develop as rapidly as the others, since there was no evidence of more than one brood of the weevil. Webster (1912), using color as a means of differentiating the adults, thought that the new generation of beetles probably laid eggs before winter because females depositing eggs in the fall from which larvae afterwards hatched, were in a perfect condition, unrubbed, and apparently fresh. Parks (1913, 1914) noted that in the autumn of 1912 beetles which emerged from their cocoons June 10 to 13 deposited eggs in outdoor cages the latter half of October, which to all appearances is the beginning of another generation later interrupted by the approach of winter but again continued in the spring. However, he also noted that eggs deposited in the autumn of 1911 were killed by the winter temperatures and that, as far as known, all eggs deposited in the autumn in the Great Basin perish before hatching or else the larvae are killed by the winter, according to the weather conditions. Reeves, Miles, *et al.* (1916) report that about half of the females of the new generation are ready to deposit eggs by the middle of October and that egg-laying then is chiefly in dry stems and continues for about a month. Snow (1925) has shown that the growth of a generation of female alfalfa weevils throughout the two seasons of their existence indicates that those emerging in the spring and summer remain immature for about four months at least, after emergence, or until late September and October of their first season; about half of them, with the exception of weevils on ditch banks, are capable of oviposition by the time winter sets in; weevils from ditch banks and fence rows were found without eggs during winter and early spring. On the other hand, the small number of females of the previous season which survive until August and September of their second summer is enough to account for the few eggs which are found at that time. These eggs, therefore, and any larvae which come from them, are retarded members of the old generation and not a partial new brood as suspected by some writers. In general it may be said that the larvae found during the summer are from eggs laid by females of the old generation, but it is possible that some of the young found late in the fall may be produced by the new generation of adults.

OBSERVATIONS IN MIDDLE CALIFORNIA

In middle California the alfalfa weevil lays eggs throughout the summer and to a smaller extent during the entire winter. It has not been determined how egg-laying is distributed during the different seasons.

Beetles were collected from time to time during the summer and as late into the fall as adults could easily be found in the field. In all cases eggs were obtained when the adults were caged with alfalfa. During August the egg-laying may have been at a minimum, but since no egg records were taken then it is impossible to make a definite statement concerning this particular point. The weevils were collected at random, with no attempt to separate the new and the old generations, and therefore no data

Fig. 12.—Field breeding cage used for field studies of the alfalfa weevil in middle California. It is constructed of redwood and fine wire screen and measures 3 x 3 x 1½ feet.

were obtained as to when the new generation might have begun egg deposition. So far little has been learned about the egg-laying habits of the pest during the winter. From field cages eggs were observed on January 6 and 13, 1933. All eggs were deposited in old alfalfa stems that were seriously injured by the frost. The bright color of most of the eggs indicated that they were only recently laid.

It is very possible that the activity of the insect is never completely at a standstill. All through the winter some larvae have been collected. They have never been taken in large numbers; usually a few could be collected at Pleasanton and Niles at any time, but at Tracy, in the San Joaquin Valley, no larvae or adults were taken during the winter of 1932–33. In winter the clover-leaf weevil larvae generally occur throughout the alfalfa fields, and it is at first difficult to distinguish the young larvae of this insect from those of the alfalfa weevil, but a little experience soon enables the collector to distinguish the two at sight.

Whether it is possible for the alfalfa weevil to pass through the winter in the pupal state still remains to be accurately determined, although some evidence has been obtained which indicates it does. Between October 25 and November 4, 1932, several hundred larvae were collected and placed in a field cage at Pleasanton. Some of these pupated and emerged before the cold weather set in. During December no observations were made, but on January 6 and 13, 1933, examination showed a considerable number of pupae. Some of them were dead, but many cocoons contained live pupae. All indications are that larvae maturing very late in the fall may pass through the winter in the pupal state.

CLIMATIC EFFECTS

GENERAL CONSIDERATIONS

Weather conditions greatly influence the activity of the alfalfa weevil. Data obtained from various investigators seem to show that climatic conditions largely determine the destructiveness of the pest. The weevil occurs over a wide climatic range, throughout a portion of which it will perhaps never become a serious pest. Even in the more favored regions it may not at times cause enough damage to warrant control measures. It is possible that the climatic conditions in southern Europe are such as to minimize the damage caused by this pest, although it is difficult to separate this influence from that due to cultural and biological control. A comparison of temperature and rainfall data in regions where the weevil occurs (table 4) shows a close correlation between the climate of a portion of California and that of a part of the Mediterranean region. On the other hand, the type of climate found in the Great Basin differs greatly from that of southern Europe.

In order to give some idea as to the likeness or difference of climates in the New and Old Worlds, table 4 has been prepared to show some of the more important climatological data for certain points. From this table it may be seen that the climate of Tashkent, Turkestan, is very similar to that of Salt Lake City and Boise, and that with all other factors equal, it might be expected that the damage by the weevil would be about the same in these places. Unfortunately very little information is to be had in regard to the damage done by the alfalfa weevil in Tashkent, although the literature contains several references to its being injurious. In the area around Salt Lake City the weevil causes very serious damage. Judging from the data shown in the table, probably the most important differences in the climate of these three places are somewhat higher mean annual temperatures and a somewhat higher mean temperature for the

TABLE 4

CLIMATIC CONDITIONS IN REGIONS INFESTED BY THE ALFALFA WEEVIL

Location	Elevation	Temperature					Rainfall				
		Mean annual temperature	Mean warmest month	Mean coldest month	Mean of maxima observed each year	Mean of absolute minima observed each year	Total rain	Mean maximum		Mean minimum	
								Month	Amount	Month	Amount
		° F	° F	° F	° F	° F	in.		in.		in.
Tashkent, Turkestan	1,574	56.3	81.5	30.2	104	− 4.0	14.56	Mar.	2.75	Aug.	0.00
Montpellier, France	131	56.12	72.86	41.0	96.8	19 4	30.31	Oct.	4.33	July	0 78
Toulouse, France	656	54.14	69.98	40 1	96.8	17.6	22.83	May	3.14	July	1.18
Florence, Italy	230	57.74	76.1	40 82	98.6	21.2	35.00	Nov.	4 33	July	1.57
Foggia, Italy	295	60.26	78.8	43.52	...	...	18.50	Nov.	2.36	July	0.78
Milan, Italy	492	54.5	74.84	32 36	93.2	14	39.76	Oct.	4.72	July	2.75
Naples, Italy	492	60.44	75.56	46.76	93.2	30.2	32.67	Nov.	4.72	July	0.39
United States											
Boise, Idaho	2,739	50.9	73.4	29.66	100 4	− 2.2	13.73	Jan.	1 98	July	0 26
Salt Lake City, Utah	4,408	51.8	76.26	28.94	98.6	− 2.2	16.23	Apr.	2.01	July	0.52
Cheyenne, Wyoming	6,088	44.96	67.46	25 52	93 2	−18.4	13.99	June	2.39	Jan.	0.38
Laramie, Wyoming*	7,188	40.8	62.9	22.6	...	...	11 06	May	1 47	Jan.	0.41
Fresno, California	293	63.14	81.86	45.86	109.4	24.8	9.28	Jan.	1.83	July and Aug.	0.01
Red Bluff, California	307	62.42	82.04	45.32	109.4	26.6	24.86	Jan.	4 86	July	0.03
Sacramento, California	71	59.54	72.32	45.66	104.0	28.4	18.56	Jan.	3.82	Aug.	0.01
Stockton, California*	23	59.6	73.3	45.8	...	...	14.44	Jan.	3.06	July	trace
Livermore, California*	485	59.7	70 3	48.6	...	...	15.26	Jan.	3 20	July	0.01
San Jose, California*	95	57.2	66.4	47.8	...	...	15.13	Jan.	3.05	July	trace
Tracy, California*	64	...	...	...	...	...	10.26	Jan.	1.96	July and Aug.	0.01
Niles, California*	70	...	...	...	...	...	18.79	Jan.	3 69	July	trace
Los Angeles, California	338	60.26	68.54	53 06	100.4	33.8	14 95	Jan.	3.06	July	0 01
San Francisco, California	206	54.86	59.36	49 46	89.6	33 8	22.52	Jan.	4 99	July and Aug.	0 02

* Temperature data from Koppen, cited below for foreign cities.

Sources of data:

Foreign cities: Koppen, W. Grundriss der Klimakunde. 388 p. Walter De Gruyter Co., Berlin and Leipzig. 1931.

Cities in United States: all data on elevation and rainfall, and data on temperature except for cities starred (for which see footnote starred), from: United States Department of Agriculture Weather Bureau. Summaries of climatological data by sections. U. S. Dept. Agr. Weather Bur. Bul W, vol. 1, ed. 2. 1926.

warmest month at Tashkent than at the American stations. Higher maximum temperatures may be expected in Tashkent than in either Salt Lake City or Boise. It is possible that these higher temperatures may be an important factor in the control of the weevil in Tashkent.

If Salt Lake City and Boise are compared with lowland stations of southern Europe, it may be seen that these American stations have a lower mean annual temperature, and that the mean for the coldest month is much lower. It seems that these low winter temperatures may be an important factor in determining whether or not the weevil is a serious pest. Such low temperatures keep the overwintering beetles inactive, and when warm weather finally sets in there is a heavy and sudden deposition of eggs, which results in the hatching and feeding of a very great number of larvae at one time.

When the temperatures of lowland stations of the Mediterranean area are contrasted with stations located near the coast of California, considerable similarity is noted. The mean annual temperatures and other climatic factors in the two regions are so much alike that it seems certain that if the climate of southern Europe is important in reducing or controlling the weevil, the same factors must also be operative in this state. If the data for inland stations of California are contrasted with those of the lowlands of southern Europe it is seen that the summer temperatures are likely to be much higher in California. At Fresno, the mean for the warmest month is higher than that of any station listed for southern Europe, and the highest summer temperatures greatly exceed any other in the table, except that for Red Bluff. It is likely then that the hot summers of the California interior valleys may be severe enough to check the alfalfa weevil to such an extent that it will not become a pest in any sense of the word, even though it may in time spread throughout these areas.

When rainfall is compared it is noted that several southern European points receive a greater precipitation than that listed for some California stations, but in spite of this much similarity is to be found in the precipitation of the two areas. However, it has been reported that moisture favors fungus diseases of this pest, and an examination of the table shows that southern Europe receives considerably more summer rainfall than the low-lying regions of California. This may be a factor in controlling the pest in its native home. The most important difference to be noted is in the hotter, dryer, interior valleys of California. Their greater dryness, coupled with very high temperatures, may also affect the weevil adversely.

Reeves (1927*b*) states that within the limits of its spread in 1927 it

occurred wherever alfalfa was grown in the United States, regardless of altitude and local climate. As a serious pest, however, it seemed to be confined to the lower valleys, presumably because of their warmer climate. It was noticeable also that even there it reached great destructiveness only in the warmer seasons. Cook (1925), after a careful review of the literature, and a study of the conditions under which the insect occurs in its original home, states:

> In the case of the alfalfa weevil the limiting periods are two in number—the temperature limit, which applies largely to the hibernating adults, and the humidity limit, which applies to the larva and its fungus enemies.
>
> * * * * * *
>
> Broadly speaking, the alfalfa weevil is limited on the north, inside the Pacific and sub-Pacific rainfall regions, by low summer temperatures; on the east, at the edge of the sub-Pacific type, by heavy summer rainfall; and on the northeast, in the plains of Montana and Wyoming, by the summer rainfall and by low winter temperatures, plus a very light snowfall. No data have been found upon which to base a limit on the south, but it is possible that the high temperatures of southern California and Arizona may prove fatal to larvae.

He further divided the region over which the pest might occur into three zones: (1) The areas of normal occurrence where climatic conditions are most favorable to the insect development, (2) regions whose normal climate departs slightly from the optimum, and may be regarded as subject to periodic infestations when the climatic variations are towards the optimum, and (3) areas whose normal climate varies widely from the optimum, and in which favorable conditions rarely occur. In this latter area he states that the weevil will probably not be able to maintain itself, but may be repeatedly introduced and become of minor importance after a series of favorable seasons. According to Cook's investigations the alfalfa weevil is fast reaching the outer zone over which it might occur. That the climatic conditions of eastern Wyoming may be reaching the limits within which spread of the weevil can take place is further indicated by Sweetman (1929):

> The alfalfa weevil has lost ground on the eastern front of the infested territory of Wyoming in the last two years. It was found at Torrington in 1926 and 1927 and at Manville in 1927, but these infestations have apparently disappeared, as scouting work in 1928 and 1929 failed to reveal its presence. While it is impossible at the present stage of these investigations to account for the disappearance, a climographic study of the two places shows that the winter of 1927 was extremely dry and December temperatures were below the average. The weevil has failed to overwinter under outdoor conditions at Laramie where the winters are normally dry.

Other findings of Sweetman (1929) showed that the removal of a crop of hay produced temperature changes close to the ground which might be extremely disastrous to immature stages of the pest; he states: "The

soil surface in alfalfa fields, when exposed to the sun, often reached temperatures between 50° and 60° C [122° and 140° F], unless the soil was quite moist." He found that the temperatures of the alfalfa stems, leaf surface, and growing tips were very close to those of the air surrounding them between 7° and 42° C (44.6° and 107.6° F).

Reeves and Hamlin (1931*a*) also point out the importance of climate. Their investigations show that the temperature conditions at the time the first crop is removed may result in a very great mortality of the immature stages of the pest. Further, they found that it is largely the few eggs which are laid on the second crop that give rise to the adults which cause the infestation the following spring. Owing to the warmer weather during the growth of the second crop, larval development is rapid, and the larvae pupate and emerge before cultural kill comes into play at the second cutting, which, coupled with a very small amount of parasitism, allows these individuals to survive. Reeves and Hamlin sum up the matter of parasitism as follows:

> In the unsuspected significance of this population lies the solution to that perplexing question, how we could experience nearly perfect parasitism one year and still have sufficient new-generation adults produced to cause weevil injury the following year. The explanation is now simple: namely, that the apparently unimportant second-crop larval population is so little affected by either biological or cultural kill, that it serves to maintain the adult population at an economically dangerous level.

It should be pointed out that if the first crop is not cut until after some of the adults have emerged, the importance of the second-crop adults is not so marked.

UPON THE ADULTS

That the adult weevils react readily to temperature is seen from the work of a number of investigators. Titus (1909*b*, 1910*a*) and others report that they are very susceptible to warmth, and that even the passing of the sun behind a cloud may be the cause of their leaving the upper foliage and seeking protection below. Overwintering adults become active with the first warm days of spring, and the degree of their activity throughout the season is largely dependent upon temperature. Titus (1910*a*) further noted that the weevils are very susceptible to climatic conditions during the period when they are going into hibernation, and a cold rain following a very hot day will so chill those that have not been able to get into proper shelter that many will not survive the night. During the warmer part of early spring days weevils have been noticed mating, and egg-laying commences soon after they come from hibernation. Reeves, Miles, *et al.* (1916) say that there is no definite hibernation in the case of the weevil. The adults are active when it is warm and quiet

when it is cold. A female taken from a frozen field will feed immediately and oviposit in a few hours after being brought into a warm room. However, it is further stated that many of the weevils die in the fields during zero weather, although milder winter temperatures seem to have little injurious effect upon them.

Sweetman (1929) found that the adult weevils became active in the morning when the temperature reached 10° to 12° C (50° to 53° F). He also observed that activities on the plants and in the shade on the ground increased as the air became warmer, and that there was some evidence of the avoidance of direct sunlight on the soil surface when the temperature reached about 35° C (95° F). During the months of May, June, and July, in 1927, 1928, and 1929, he observed no evidence of flight to escape high temperatures. Further observations showed that cloudy weather apparently had no effect on the reactions of the adults; their activities seemed to be regulated by the temperature rather than the amount of sunshine. Sweetman (1932), observing the activities of the beetles during warm nights in the middle of June, reports that movement, feeding, and mating continued as during daylight hours when the temperature was high enough.

Sweetman and Wedemeyer (1933) report that under controlled conditions relative humidities below 40 per cent, at least with temperatures of 27° C (80.6° F) or higher were very destructive to the adults, and Reeves (1917) noted that a temperature of 120° F is fatal to the insect, while in Idaho (Idaho Agricultural Experiment Station, 1926) the unusually low temperatures of December, 1924, are stated to have resulted in 95 per cent mortality of the pest.

UPON THE LARVAE

The effect of temperature upon the larvae is important. According to Sweetman (1929):

> The larvae may seek shade and cool places when the temperature reaches about 30° C [86° F], but they are often exposed to direct sunlight when the temperature is higher. They seclude themselves in buds, axils, and lower on the plants at times to avoid heavy rains, strong winds, and extreme heat. . . . There is also some evidence of seclusion in rubbish and crevices in the soil during the midday heat following the harvesting of the crop.

Sweetman (1932) also states that the length of the developmental periods was closely associated with temperature and that "The minimum effective temperature for development during the feeding period is about 10° C [50.0° F], but during the pupation period is about 13° C

[55.4° F]." He was also able to study the effect of freezing temperatures upon the larvae and reports:

> An excellent opportunity developed on June 20 to determine the effect of freezing temperatures on the larvae. The minimum temperature at the top of the plants was about —2° C [28.4° F], and remained below freezing for about 2 hours, killing the upper inch or two of many of the plants. A large number of frozen portions of the stems were removed and examined before the larvae became active in the morning. Many larvae were found and all of them appeared to be normal in every way and resumed feeding when placed on fresh plants.

Observations of the larvae during the warmest nights revealed that they were secluded and inactive during darkness under the conditions observed. As daylight appeared they became active and were exposed on the outer parts of the plants if the temperature was favorable. (Sweetman, 1932.)

Sweetman and Wedemeyer (1933), working under controlled environments, found that "the favorable region for larval development was between temperatures of about 20° to 30° C [68° to 86° F] with relative humidities ranging from 95 per cent to at least as low as 30 per cent. Temperatures above about 34° [93.2° F] destroyed the larvae."

UPON THE PUPAE

Pupae that are left unprotected in the field after the removal of the hay crop may be considerably affected by temperature. The hot, dry weather of the western summers appears to kill many of the pupae left unprotected on the ground after the first crop is removed (Parks, 1913). Sweetman (1929) collected cocoons, which remained unprotected on the ground for varying periods of time, and found the emergence of the adults to be 17 per cent greater from cocoons exposed less than one day than from those left in the field for a longer period.

TEMPERATURE IN RELATION TO EGG-LAYING

All investigators appear to believe that egg-laying is greatly influenced by weather conditions, particularly temperature. Parks (1913) states that a prolonged cool spring results in the extension of egg-laying over a long period of time, so that the number of larvae feeding at any one time is less, and the injury resulting not so great but that the plant will have a chance to recuperate. Experiments carried out at Salt Lake City showed that the rate of egg-laying was directly dependent upon the mean daily temperature during the time of egg deposition. He found that a cold day will check egg-laying while one or two warm days will greatly increase it. Titus (1913) noted that when warm weather con-

tinues throughout the day, and the alfalfa is from 6 to 8 inches tall, egg-laying is begun in earnest. Webster (1912) points out that in 1909 egg-laying began in the fields early in April, and eggs were found in greatest abundance during the last of May and the first of June. However, in 1910 egg-laying began early in March and was at its height by the middle of May. Hagan (1918) reports that if the weather is warm and dry, egg-laying is completed within a few days, but if the season is cold and wet it may be extended over several weeks. Sweetman (1929) found that the number of eggs laid increased during warm weather, and that the correlation between egg-laying and temperature is very marked. He reports that on one day having a mean temperature of 39.2° F during a time of heavy egg production, 13 females failed to lay any eggs while 2 others laid 15, but that on the day preceding and following this cold one over 100 eggs were laid by the 15 females. He also showed that many eggs laid in dead stems are destroyed by the high temperatures to which they are subjected.

Later Sweetman and Wedemeyer (1933) found that under controlled conditions: "The favorable region for oviposition of the adults apparently was below a temperature of 28° C [82.4° F] with relative humidities between 50 and 95 per cent. Temperatures of 30° to 37° C [86° to 98.6° F] were very injurious, especially when the relative humidity was high, while higher temperatures killed the adults in a few days."

EFFECT OF ELEVATION

In the discussion of general climatic conditions the effect of elevation has been mentioned in several places. In general it has been noted that with an increase in elevation, beyond a certain level, weevil injury becomes less, owing to cooler spring temperatures and more severe winters. According to Webster (1912) "Latitude and elevation, with the consequent modifications of temperature, will have much to do in deciding the time of emergence from winter quarters in spring." Parks (1913) states that when the larvae are numerous they may stop the growth of the plants, and adds that this occurs in June in fields having an altitude of from 4,000 to 5,000 feet, and during July in fields having an altitude of from 5,000 to 6,000 feet. He further remarks that there is no reason to expect that the cold winters which prevail in the high altitudes in much of southeastern Idaho will control the pest, since they thrive in the mountain valleys of Utah at an altitude of from 6,000 to 7,000 feet. However, during the time of his investigations there were a number of years during which climatic conditions were very favorable to the insect, and since the publication of his work it has been noted that the cold tem-

peratures of certain high altitudes may effectively control the pest. Titus (1913) reports that in the higher mountain valleys, the weevils reach the adult stage later in the summer, and enter into hibernation earlier. Cook (1925) reports: "The damage decreases with an increase in elevation. An increase in altitude in this region is equivalent to a shortening of the growing season plus an increase in precipitation."

WEATHER CONDITIONS IN RELATION TO CONTROL

That weather conditions exert a marked influence on the weevil is best illustrated by the effects upon its control. If a season is favorable to the development of the pest in those areas where it has become abundant, then it may be necessary to resort to artificial methods of control to obtain a profitable crop. Reeves, Miles, *et al.* (1916) point out particularly that in years when there is an early spring, the weevils are stimulated to early activity, and this fact must be taken into account in any attempt to protect the first crop. Under such conditions larvae hatching from eggs laid early along with those laid the previous fall, sometimes attack the plants in numbers large enough to cause serious injury to the crop before the majority of the eggs have been laid.

Certain climatic conditions greatly influence the time of the season that damage becomes most apparent. It is claimed that in warm seasons the plants get an early start, which tends to postpone the critical point, at which time spraying should be done, but since this condition is more than offset by the rapid development of the weevils, the damage is also likely to come early. On the other hand in a cold backward season the growth of the plants is hindered by the weather, but not to the same degree as are egg-laying, hatching, growth, and feeding of the weevils, and thus the crop becomes nearly mature before its growth is halted by them. It is also stated that a heavy frost during the growing season has but little effect upon the weevil. It merely delays the weevil's activities for a few hours, but it may seriously stunt the alfalfa plants and puts them at the mercy of the weevil larvae, somewhat as does the cutting of the first crop. Wakeland (1920) reports a condition where a freeze occurring on June 1 greatly reduced the rate of plant growth and the injured alfalfa was therefore unable to withstand weevil attack as normal healthy plants should.

Snow (1925) states that cool and damp weather throughout the spring followed by bright weather after the time of haying appears to have controlled the weevils in Utah during certain years. Chamberlin (1924*a*) points out that in general warm and dry weather in the late winter and early spring followed by cool and damp weather at haying time, allows

the weevil not only to develop early and rapidly, but also protects it from great mortality often caused by heat at the time of cutting the first crop. Conditions which do not favor excessive damage are: (1) cool moist spring weather which aids the growth of the alfalfa and slackens the egg-laying of the beetles as well as the feeding of the greatly reduced number of larvae; (2) clear hot harvest weather, which kills many of the larvae and thus makes it unnecessary to protect the second crop. Reeves (1927*b*), commenting on the fluctuation in injury, says:

This variation in damage is explained by the stimulating effect of warmth upon egg production. The nine years during which this weevil was invariably destructive were for the most part abnormally warm during the egg-laying season in April and May, as were also those of the later years in which the damage was serious. The climate of the Great Basin region is such that there is only a short time when the temperature is favorable to egg-laying, before the first crop matures and can be removed from danger. Under such conditions a late spring, by delaying the egg-laying, may allow the hay crop to be harvested before enough larvae can hatch to do it much harm. This happens often in the warmer valleys and nearly always in the colder regions.

HOST PLANTS

The food plants of the alfalfa weevil are mainly members of the pea family, Leguminosae, upon which the larvae and adults feed. The larvae are more restricted in their feeding habits than are the adults, and in listing the hosts it is necessary to be somewhat specific in this respect. The adult females normally oviposit in the stems of the food plants of the larvae, but they often attach their eggs to the leaves and stems or oviposit in plants on which the larvae cannot subsist. For instance, in confinement the adults have been observed to feed on and to oviposit freely in the stalks of geraniums, whereas the larvae will soon starve if restricted to that diet. In the field Titus (1913) reports that eggs have been found deposited in many grasses, grains, and weeds, but very few of the larvae hatching in such places survive, because their slow mode of progression usually prevents them from reaching suitable food plants.

Reeves (1927*b*) states that "It is believed, though not definitely proved, that the weevils' ability to feed upon wild legumes accounts for the ease with which it spreads through thinly settled regions where alfalfa fields are many miles apart."

In order to give some idea of the host selection of the insect, table 5 has been prepared to show the general range of plants on which it might feed. The table also includes such plants as potato, raspberry, cabbage, and cotton, which are attacked only by the adults; but none of these plants have been recorded as supporting the pest in this country. Of the

TABLE 5

Host Plants of the Alfalfa Weevil

Host	Parts infested	Relative importance of injuries	Stage of weevil feeding	Localities where injuries were noted	Authority and reference to literature
Alfalfa, *Medicago sativa*	Leaves, stems	Often serious; may destroy crop	Larva, adult	Throughout range in Asia, Europe, North America	....
*Astragalus creophilus**	....	....	Larva	Utah	Webster (1912)
Astragalus utahensis See vetch	....	....	....	....	....
Black locust, *Robinia pseudacacia*†	....	....	Larva	Utah	Webster (1912)
Bean, *Phaseolus vulgaris*†	Leaves, stems	Slight	Adult	Germany	Lüstner (1923)
				Utah	Webster (1912) Titus (1913)
Clover					
alsike, *Trifolium hybridum*†	Leaves	....	Larva, adult	Utah	Titus (1910*a*) Webster (1912)
bird, *Lotus corniculatus*	Foliage	....	....	Germany	Krüger (1933)
bur, *Medicago hispida*†	Leaves	....	....	Great Basin	Parks (1913)
Medicago hispida var. *confinis*† var. *nigra*† var. *terebellum*†	Leaves	....	Larva	Utah	Webster (1912)
crimson, *Trifolium incarnatum*	Leaves	....	Larva, adult	Utah	Titus (1910*a*)
red, *Trifolium pratense*†	Leaves	....	Larva, adult	Great Basin	Parks (1913)
				Utah	Titus (1910) Webster (1912)
white, *Trifolium repens*†	Leaves	....	Larva, adult	Great Basin	Parks (1913) Titus (1910*a*) Webster (1912)
white sweet, *Melilotus alba*†	Leaves	Slight	Larva, adult	Utah	Titus (1910*a*, 1913) Webster (1912)
				Great Basin	Parks (1913) Reeves (1927*b*)
yellow sweet, *Melilotus officinalis*	Leaves	....	Larva, adult	Utah	Titus (1910*a*)
				Great Basin	Reeves (1927*b*)
Melilotus indica	Leaves	....	Larva	Utah	Webster (1912)
Melilotus sp.	Leaves, stems	Slight to severe	Larva, adult	France	Picard (1914*a*)
Cabbage, *Brassica capitata*	Leaves	Slight	Adult	Germany	Lüstner (1923)
Cotton, *Gossypium* sp.	Small seedlings, buds, top roots	Severe	Adult	Turkestan	Yakhontov (1929)

* These plants were eaten by the larvae when no other food was offered, but refused in the presence of alfalfa.

† In cages the larvae fed freely on these plants, in the presence of alfalfa.

TABLE 5—(*Concluded*)

Host	Parts infested	Relative importance of injuries	Stage of weevil feeding	Localities where injuries were noted	Authority and reference to literature
Downy lupine, *Lupinus* sp.*	Leaves		Larva	Utah	Webster (1912)
Fenugreek, *Trigonella foenumgraecum*†	Leaves		Larva	Utah	Webster (1912)
*Hedysarium mackenzii**	Leaves		Larva	Utah	Webster (1912)
Lotus corniculatus	Foliage			Germany	Krüger (1933)
Medicago echinus†	Leaves		Larva	Utah	Webster (1912)
muricata†	Leaves		Larva	Utah	Webster (1912)
orbicularis†	Leaves		Larva	Utah	Webster (1912)
scutellata†	Leaves		Larva	Utah	Webster (1912)
See also alfalfa, clover, and nonesuch					
Nonesuch or black medick, *Medicago lupulina*†	Leaves		Larva, adult	Utah	Webster (1912) Titus (1913)
Pea, chick, *Lathyrus sativus**	Leaves		Larva, adult	Utah	Webster (1912) Titus (1913)
sweet, *Lathyrus odoratus*†	Leaves		Larva	Utah	Webster (1912)
Potato, *Solanum tuberosum*	Leaves		Larva	Germany	Lüstner (1923)
Raspberry, *Rubus* sp.	Leaves		Adult	Germany	Lüstner (1923)
Spider plant, *Cleome serrulata**	Leaves		Larva	Utah	Webster (1912)
Vetch, wild	Leaves		Larva, adult	France Great Basin	Picard (1914*a*) Parks (1913)
hairy or winter, *Vicia villosa**	Leaves		Larva	Utah	Webster (1912)
narrow-leaved, *Vicia* sp.†	Leaves		Larva	Utah	Webster (1912)
obtuse-leaved, *Vicia* sp.†	Leaves		Larva	Utah	Webster (1912)
purple, *Vicia atropurpurea**	Leaves		Larva	Utah	Webster (1912)
spring, *Vicia sativa alba**	Leaves		Larva	Utah	Webster (1912)
Utah milk, *Astragalus utahensis*†	Leaves		Larva	Utah	Webster (1912)
*Vicia dispema**	Leaves		Larva	Utah	Webster (1912)

* These plants were eaten by the larvae when no other food was offered, but refused in the presence of alfalfa.

† In cages the larvae fed freely on these plants, in the presence of alfalfa.

cultivated crops, alfalfa seems to be the only plant that is severely injured. Plants belonging to the genera *Medicago* and *Melilotus* apparently are favored the most.

STUDIES OF CALIFORNIA HOST PLANTS

In order to secure further data on the host range of the insect, work was started in July, 1932, to determine what plants were preferred by the weevil. Up to the present time 35 plants have been experimented with, all of which were legumes. Some of these investigations were started so late that it is hardly to be expected that conditions were favorable for weevil development, and in the case of a number of plants the tests will be repeated. To date 7 different species of plants belonging to 3 genera have been found on which the weevil can pass through all stages of development. They are *Medicago sativa, M. hispida, Melilotus alba, M. indica, M. hubamensis, Vicia dasycarpa,* and *V. villosa.* It further appears that *Trifolium repens, T. hybridum,* and *Vicia calcarata* are suitable host plants. In the case of the first two the plants became so heavily infested with aphids that the work of the alfalfa weevil was masked. However, larvae of different sizes were observed on these plants and it is likely that under favorable conditions these would complete their development, and it is possible that they did so, although no cocoons were observed. The adult weevils fed to a greater or lesser degree on all the plants experimented with.

The following procedure was used in determining the host plants. The plants were grown from seed in 10-inch flower pots. After they reached a fair size, adult weevils were caged on them. The number of the latter varied from about 25 to 100 per cage, largely according to the denseness of vegetation.

The adults fed on all plants; some plants on which no larvae were seen were severely attacked. Among these plants were large and small lima beans, sweet peas, soybeans, and a few others. So severe was the injury by the adults that all plants falling in this category will be further experimented with. It seems possible that under proper conditions the pest will pass through its entire life history from egg to adult on at least some of these plants.

For the most part, when the weevils were placed in the cages, they laid eggs over the different parts of the plants and in a number of cases deposited the eggs on the surface of the soil. In a few instances eggs were also deposited within the stems of jack bean, and the large lima bean.

Table 6 has been prepared to show the results obtained to the present time. Further work may change this somewhat.

Under natural conditions the weevil has been found breeding on three different hosts besides alfalfa. These are: bur clover (*Medicago hispida*), yellow sweet clover (*Melilotus indica*), and white sweet clover (*Melilotus alba*). Their importance is probably in the order given. On April 21, 1933, the larvae of the alfalfa weevil were found with great ease feeding on bur clover, and to a lesser extent on yellow sweet clover from Pleasanton to Niles via Niles Canyon. On May 10 an examination showed the weevil to be rather abundantly distributed on yellow sweet clover over

TABLE 6

Possible Host Plants Experimented with in California

Name of plant	Favorable as a host (weevil able to pass through entire life cycle on it)	Amount of feeding by adults	Date of infestation	Number of weevils per cage
Alfalfa, *Medicago sativa*	Yes	Heavy	July 22, 1932	35
Bean:				
adzuki, *Phaseolus angularis*		Moderate	July 19, 1932	35
asparagus, *Vigna sesquipedalis*		Moderate	July 12, 1932	30
baby lima, *Phaseolus lunatus*		Heavy	July 15, 1932	30
blackeye, common, *Vigna sinensis*		Moderate	July 15, 1932	52
Brabham, *Vigna sinensis*		Moderate	July 12, 1932	60
California lima, *Phaseolus limensis*		Heavy	July 8, 1932	30
hyacinth, *Dolichos lablab*		Heavy	July 12, 1932	40
jack, *Canavila ensiformis*		Heavy	July 19, 1932	35
kidney, *Phaseolus vulgaris*		Heavy	July 8, 1932	55
rice, *Phaseolus calcaratus*		Moderate	July 22, 1932	35
small white, *Phaseolus vulgaris*		Heavy	July 8, 1932	59
soy, *Soja max*		Heavy	July 19, 1932	35
Black gram, *Phaseolus mungo*		Light	July 26, 1932	25
Clitoria ternates		Light	August 4, 1932	30
Clover:				
alsike *Trifolium hybridum*	Probable	Heavy	October 4, 1932	67
Egyptian or Berseem, *Trifolium alexandrium*		Moderate	September 29, 1932	75
red, *Trifolium pratense*		Heavy	September 29, 1932	80
toothed bur, *Medicago hispida*	Yes	Heavy	August 31, 1932	89
yellow, *Melilotus indica*	Yes	Heavy	September 29, 1932	107
white, *Trifolium repens latum*	Probable	Moderate	October 17, 1932	23
white sweet, *Melilotus alba*	Yes	Heavy	....	....
Cyamopsis tetragonolobus		Moderate	July 26, 1932	30
Green or golden gram, *Phaseolus aureus*		Moderate	July 22, 1932	35
Lupinus sp.		Light	July 8, 1932	50
Melilotus hubamensis	Yes	Heavy	September 29, 1932	75
Mexican garavanzas, *Cicer areitinum*		Light	July 26, 1932	50
Pea:				
pigeon, *Cajanus indicus*		Light	July 22, 1932	35
sweet, *Lathyrus odoratus*		Heavy	July 15, 1932	30
Peanut, *Arachis hypogaea*		Heavy	July 19, 1932	40
Vetch:				
Vicia dasycarpa	Yes	Heavy	March 3, 1933	50
hairy, *Vicia villosa*	Yes	Heavy	April 3, 1933	50
purple, *Vicia atropurpurea*		Heavy	July 8, 1932	30
spurred, *Vicia calcarata*	Probable	....	April 3, 1933	50

this same area. A further search showed it to be present on white sweet clover, although on this plant it was rather difficult to find. There is apparently no way to check the weevil spread on its natural hosts, on which it has now become well established. It will probably spread most rapidly where these plants grow most vigorously and where they are protected from severe grazing. One would expect these places to exist for the most part along railroads, roads, streams, and in the low river lands.

DESTRUCTIVENESS

IN OLD WORLD

From available literature and reports it is difficult to derive any very definite ideas concerning the destructiveness of the alfalfa weevil in Europe and Asia. The methods of farming are so different from those in America that it is difficult to draw conclusions. It therefore seems advisable to quote the various Old World authors, who have, during the past ten years, reported upon this insect.

In northern Europe it seems to be of little consequence as a pest.

Sweden, 1917.—A report states that it has not been recorded in that country since 1903, when it was observed attacking alfalfa in some localities in Scania (Tullgren, 1917).

Denmark, 1917.—The larvae of the alfalfa weevil were very common on alfalfa in June and July in some localities and did serious damage (Lind, Rostrup, and Kølpin Ravn, 1917).

France.—1914: The alfalfa weevil is chiefly a pest of the second crop of alfalfa in southern France (Picard, 1914*a*).

1921: Alfalfa reported as suffering from the attacks of the alfalfa weevil (Marchal and Foex, 1921).

"In our experience," writes Chamberlin (1924*b*), "weevils were most plentiful in the Rhone Valley between Valence and St. Rambert, near Lons-le-Saunier, Chambery, Annecy, and Gap. There were several fields in or near Hyères which contained a fair number of weevils."

Spain, 1929.—The alfalfa weevil was first discovered as a pest of alfalfa in 1929; not previously noted in Spain (Spain, 1929).

Germany.—1922: Damage was done to alfalfa by the larvae of the alfalfa weevil. "According to Reh, it attacks beans, cabbage, and raspberries, and the larvae eat potato foliage" (Lüstner, 1923).

1929: The alfalfa weevil was noted as a new and important pest of alfalfa in various parts of Saxony (Molz and Müller, 1929).

1933: Reported as feeding on bird trefoil in Germany (Krüger, 1933).

Bulgaria, 1931.—The alfalfa weevil caused damage to alfalfa in many localities (Chorbadzhiev, 1931).

Russia—European.—1913: The alfalfa weevil was listed among the insects injuring the leaves and stalks of alfalfa in Kiev (Vassilier, 1913).

1916: The alfalfa weevil was very numerous in the Caucasus during that year (Uvarov, 1917).

1924: The insect occurred frequently in the alfalfa fields in the districts of Lublin and Kielce (Woroniecka, 1924).

Russia—Asiatic.—1913: The alfalfa weevil was most numerous and injurious near Tashkent in March (Smirnov, 1913).

1914: The alfalfa weevil was a pest of alfalfa in Turkestan (Plotnikov, 1914).

1917: The alfalfa weevil appeared in large numbers in an alfalfa field near the station at Tashkent and greatly injured the foliage of alfalfa (Dvornitchenko, 1917).

1928: A serious deformation of young cotton seedlings in Turkestan noted in 1928, was due solely to the alfalfa weevil, which injured the buds and the tops of the roots (Yakhontov, 1929).

From these reports it will be noted that no large general outbreaks occurred anywhere during the period from 1912 to 1932 and that in no single district was the insect reported to be a serious pest during two or more consecutive years. As a matter of fact European and Asiatic entomological literature does not at all emphasize the importance of this insect as a pest of great or even ordinary economic importance.

IN UNITED STATES

Under certain conditions the alfalfa weevil becomes destructive throughout most of its range in the United States (fig. 2). The conditions which allow for considerable damage have been treated previously in this paper. Almost every article that deals with the pest in this country points out the tremendous damage it is capable of causing. Thus Reeves, Miles, *et al.* (1916) speaking of Utah say: "The damage to the first cutting ranges from slight depreciation of the quality of the hay to almost total loss, varying according to the rate of growth and the time of harvest; it may be estimated at 50 per cent. The damage to the second cutting, if no effort is made to prevent it, amounts to total loss. The menace to this state, therefore, involves one-half of the yield, worth $3,000,000." In 1927 Reeves (1927*a*) states that for "the first nine years of its history in the United States the weevil not only spread rapidly, but it is said to have nearly destroyed the first cutting of alfalfa year after year without interruption."

Fortunately conditions are not always so favorable for the pest, and

during later years it has only been really destructive in those seasons when suitable climatic conditions have existed in particular localities.

Hagan (1918) states that the injury to the alfalfa crop still aggregates an enormous sum annually, but he also points out that many farmers in the infested area are cutting more hay than before the appearance of the pest, owing to the adoption of better cultural methods.

In middle California, where the insect has been present a number of years, serious damage has been noted in poorly kept fields in several localities, where in the spring of 1933, as many as 3,000 to 6,000 larvae were taken per 100 sweeps of the insect net. It may be that large populations build up until the first cutting, after which they diminish rapidly in numbers. Last year (1932) the first counts were not made until the second cutting was well under way on June 1. In spite of the large numbers of weevils on the plants their presence has usually not been noticed by the alfalfa growers in any place unless their attention has been called to it.

DISSEMINATION OR SPREAD

GENERAL CONSIDERATIONS

As to the manner by which the alfalfa weevil was introduced into Utah, Webster (1912) states in regard to the locality where the weevil was first observed in that state, that "Although not far distant from nurseries, it is not in close proximity to any railway; it is on the other hand among the habitations of the more humble class of people, such as have come from foreign countries. The correct inference, therefore, would seem to be that it was introduced with nursery stock or in household effects of emigrants." He also reports that the habit of the beetle to hide away in any crevice or aperture that will accommodate it doubtless has considerable to do with its diffusion and that it is absolutely impossible to lay down any law that appears to regulate the diffusion of the insect. As a matter of fact the beetles are repeatedly being found where least expected, and they have not been found where, judging from their habits, they would be most confidently expected.

Parks (1913) notes that thus far no mountain ranges appear to obstruct the progress of the beetles and that the larvae and adults have been found feeding in mountain canyons on isolated alfalfa plants far removed from cultivated fields. Titus (1913) substantiates Parks and adds that alfalfa has escaped from cultivation in many places over the state (Utah) and whether it is found on the mountain sides, in the canyons, or growing wild in sagebrush areas, weevils will nearly always be found feeding on the buds and leaves. He also reports finding the weevil

as high as 9,500 feet. Reeves (1917) notes that the spread of the weevil has been slow and uniform regardless of the character of the country, whether cultivated or wild, and the insect has dispersed in an ever widening circle at the rate of about 10 to 20 miles each year, and apparently without much regard as to what are commonly supposed to be natural aids or hindrances to the dispersion of insects. No natural barriers against the weevil exist; he further notes that it has profited but little from artificial aids to its progress; and in the absence of any known method of preventing the continued spread of the weevil it may be assumed that it will reach all the alfalfa-growing regions of the continent.

Another possible way in which the weevil may be carried for rather long distances, is in the blankets of tramps, which have been spread in infested alfalfa fields or in infested hay. As far as is known no infestations have been traced to this source, although it is the belief of some entomologists that the new infestations in middle California may be accounted for in this manner.

It may be inferred from the discussion which follows that all of the ways by which the weevil has been carried to new and distant places are not fully known. Fortunately there have been but few long jumps, and most of these cannot be considered very serious. Reeves (1927*b*) reports three great skips to have been made in the progress of the weevil, aside from its original introduction: One colony was established at Paonia, Colorado, one at Reno, Nevada, and one in New Plymouth, Idaho. He further states "In effect these leaps have increased its total dispersion but slightly, as the general spread of the insect has now nearly reached the zone in which these localities lie with respect to the original center of infestation." Newton (1926*a*) calls attention to the fact that before the occurrence of the weevil in Colorado, the pest had made no outstanding jumps to new districts in America and adds that in recent years there have been isolated infestations in the states of Idaho, Oregon, Nevada, California, and Wyoming. Cole (1932) later reported a new infestation of the weevil in Jackson County, Oregon, which was another long jump.

The most recent jump of the weevil to come to light is that in middle California, including five counties in the neighborhood of the San Francisco Bay region. This infested area was not discovered until May 13, 1932, but from all appearances it is of rather old standing, for the area covered is rather extensive, and is not a continuous district. The region is divided by at least two ranges of more or less barren hills, which are of considerable size.

Table 7 shows the long jumps made by the weevil and the place and time the infestations were first observed.

DISSEMINATION BY FLIGHT AND CRAWLING

Once the alfalfa weevil becomes established in an area, its most important means of dissemination appears to be by flight and crawling. These natural means undoubtedly carry the weevil slowly outward from the infested area. Titus (1909*b*, 1910*a*) reports, "the principal means of distribution of the weevil at the present time is that of migration by the adults in the summer and fall." He also states that they are strong walkers, untiring and steady, and remarks that he has found them scattered all across a 40-acre piece of uncultivated land, moving away from the alfalfa field on one side, many of them eventually reaching an uninfested field on the opposite side of the "forty;" and that probably the most prevalent and, at the same time most noticeable, means of spread are the spring and summer flights. He further states that each spring the adults may be found flying for a period of about 6 weeks, and that the summer flight is for a shorter period. He further points out that at all times of the year when they are active, they may be seen crawling through the fields, and during the migrating seasons, both spring and summer, may be found in almost all parts of the infested region, generally moving from one place to the other during the warm sunny portion of the day. However, he continues that the distribution of the pest appears to be almost entirely by flight.

TABLE 7

Long Jumps in Distribution Made by the Alfalfa Weevil in the United States

Locality	When first observed	Reference
Delta County, Colorado	1917	
Washoe County, Nevada	1920	
Payette County, Idaho	1918	
Oregon, eastern	1928 shows several isolated areas not connected to main body	Shown in map, U.S. Dept. Agr., Bur. Ent., 1928, p. 352
Jackson County, Oregon	1929	Cole (1932)
Five counties in middle California	1932	

A. J. Cook (1911) reports that the weevils are active in early summer and may fly long distances, aided by the wind. Webster (1912) also states that there is a spring and summer flight and remarks that the spring flight of the individual female is perceptibly shorter than the second migration owing to their being more or less heavily laden with

eggs. During the summer flight the beetles fly high in the air and over long distances. Parks (1913) adds that the weevils fly during two seasons of the year. The first occurs in early spring when the pest is leaving winter quarters, and the second in July and August when the new generation of beetles has appeared, and when many fly into the air and leave the infested fields to be carried to new ones beyond. Beetles were observed on April 12, 1912, falling indiscriminately in alfalfa and grain fields, along roadsides and right-of-ways, and alighting within a few feet of open ore cars in the railway yards at Salt Lake City.

Reeves, Miles, *et al.* (1916) report that the flight of the weevil is less general and extensive than it was once supposed to be; that all records which are definite and authentic show that only small numbers of the weevils are in flight at any time; that there is no evidence that the weevils ever fly for the purpose of seeking fields of alfalfa, either new or previously infested, or to find hibernation quarters. They believe the most plausible theory is that their flight is caused by rises in temperature, as are many activities of lower animals, and as far as can be determined, this flight is at random. However, it does take some weevils to new fields. The importance of crawling as given by the same author is as follows:

> During the cold weather of spring and fall a day's journey of an adult weevil is only a few inches, but during the warm months the adults crawl through the greater part of the day or, in July and August, of the night. Although they use up much of their energy in climbing up and down plants, and into and out of crevices in the ground, so that it is largely wasted so far as progress is concerned, a little of it happens to lead to new fields. There is no general movement by crawling any more than by flight, from the fields to the ditch banks, fence rows, and similar places, or from such places to the field, at any time. This crawling is most important, as has been shown, in bringing weevils into hay, and so into traffic, which probably takes them somewhat further than they could go without help.

Hagan (1918) believes that the principal means of distribution into new territory is by flight. He states that in late summer the adult weevils take to wing to seek a shelter in which to pass the winter, and designates this as the summer flight. Although a comparatively large percentage of the weevils never leave the fields in which they have been feeding, those that do may travel several miles before hibernating. In the spring the overwintering adults appear and take their spring flight in search of food. He further writes that it is supposed that these two migrations enable the weevil to spread at the average rate of 20 miles a year; but careful study of weevil migration during the past few years has shown dispersal along favored routes to be much more rapid. Such an advantage as volunteer alfalfa along roadways, ditch banks, and railroad

tracks which furnishes food and shelter enable weevils to spread as far as 50 to 60 miles in a season.

Cook (1925) also reports a spring and summer flight of the weevil. He states that in early spring the adults emerge from hibernation and fly about actively seeking a place for oviposition. This he calls the spring flight. The summer flight occurs after the new generation appears from June to August.

Wakeland (1920) says:

At one time it was hoped that barriers such as expanses of barren land might prove an effectual check to the natural spread of the insect and that it would not make progress rapidly against the wind. Both of these hopes were proven to be ill-founded. Newly infested fields were discovered to which the weevil could have spread only by flying across barren, adobe land at a distance of three or four miles and against the prevailing wind during the warm part of the day, when it is its habit to fly.

Snow (1925) states that flight and crawling of the adults, aided by the wind and the general traffic, have been the chief means of the slow spread of the weevil.

Reeves (1927*b*) reports the gradual spread of the insect around the edges of the infested district to be largely accomplished by unaided crawling and flight, which seem likely to carry the weevil wherever alfalfa is grown. Even the absence of growing alfalfa seems to be no hindrance to the spread, probably because of the large number of other plants upon which the weevil may feed. His findings are largely in accord with earlier investigations; in regard to a portion of the flight he says:

The heat of the soil also probably accounts for a certain amount of flight by the adults during the dry, hot weather beginning in June and ending in August. This flight takes them to grassy and shaded places where they find protection from the heat. It also helps to restock fields in which the weevils have been killed, and on the borders of the infested districts it contributes to the spread of the pest. The flight is not a general movement of the weevils from the fields to seek more suitable hibernation places elsewhere. There is no such movement, and virtually all of the weevils spend the winter in the field.

Sweetman (1929) carried on some experiments in Wyoming, as follows:

Screen wire covered with tanglefoot was placed 4 to 7 feet above the ground to entangle the adults while flying. No beetles were captured during May, June, and July in 1927, 1928, and 1929. . . . No evidence of flight to escape high temperatures or for other reasons was observed during May, June, and July in 1927, 1928, and 1929. Flights may take place in August and September as only a few observations have been made during these months.

He concluded from his results that if flight is considered a very im-

portant means of dispersal, the spread of the pest should be slow in Wyoming.

Henderson (1919) states that the weevils are rarely on the wing and that their distribution flight is almost negligible. He further cites some work carried out in the summer of 1914, by members of the United States Department of Agriculture Bureau of Entomology at Salt Lake City, in which a screen 4 x 40 feet was coated with tree tanglefoot and was erected in the midst of the worst alfalfa-weevil infestation in Utah. "During the season from March 25 to November 22, only 632 weevils were captured on a screen, having an area of 160 square feet, or fewer than 4 weevils per square foot for the season."

In this review of the literature on flight there are some conflicting reports. Many of these may be accounted for by the different conditions in the various locations where the investigations were conducted. Some of the work was published soon after the weevil made its first appearance and it is possible that there was not sufficient time for the workers to determine fully the importance and degree of flight.

NATURAL SPREAD IN CALIFORNIA

During the early stages of our investigation, which were started (June 1, 1932) in the San Francisco Bay area, the adult weevils in the field were observed only three times to be stimulated to flight, and on two occasions they were observed to fly only very short distances. These observations were made at Pleasanton, one in June, another on August 10, 1932, and the third on February 22, 1933. All days were clear and almost still. The temperature was about 70° to 75° F, in the first two cases and about 65° F in the third. How extensive flight may be under California conditions is still unknown, but it is likely that it plays an important part in the spread of the pest, for the individuals observed on February 22 appeared to be strong fliers. But later, when the weevil populations in the fields built up in larger numbers, flight became more apparent and, during June, 1933, considerable activity on the wing was noted. However, it should be pointed out that in certain areas, like the Livermore Valley and the district adjacent to Niles, there is a rather uniform occurrence of the beetle in all alfalfa fields, which can best be accounted for by natural flight, since in both districts the maximum distance covered is from 6 to 10 miles. Under certain conditions the weevil may be stimulated to fairly active flight. This is indicated by observation of adults in a field cage during November. On still, clear, warm days they were observed to become very active and to fly about freely at noon when the temperature was 70° F or above.

WIND AS A MEANS OF DISSEMINATION

The effect of the wind also enters into this phase of the discussion. The influence of air currents is closely interrelated with flight and has been touched upon under that subject. Webster (1912) states that the most rapid dispersion of the insect has been towards the northeast from the original point of infestation in the Salt Lake Valley. He says:

> [This northeastward trend of diffusion] must be considered in connection with prevailing southwest winds at the time when the beetles are flying, and, in fact, careful search over the newly infested territory seems to render it highly probable that to this cause is due this northeastward diffusion. The finding of individual larvae well scattered over Wyoming fields with little or no indications of introduction by human agencies, together with the finding of larvae in an irrigated valley, isolated from other cultivated crops by 35 miles of dry desert country, are conditions hard to explain in any other way than that the south winds of spring and summer have resulted in carrying flying beetles over low mountain ranges to fertile fields beyond. To just what extent the winds are able to carry the adults into new territory is not known, but at any rate migration in other directions has taken place much less rapidly.

Parks (1913) remarks that "thus far distribution appears to be almost entirely by flight and the wind has proved to be the main agency of dispersion by carrying beetles from infested fields to fields beyond the original area of infestation." He also states that the rate of dispersion must be influenced by the velocity and the direction of the wind during the time the beetles are on the wing. Titus (1913) reports that weevils have been taken as high as 9,500 feet in Salt Lake County. These had apparently been carried there partly by winds while they were flying and had lodged on the sides and summits of the mountains.

Reeves, Miles, *et al.* (1916) state that the greatest progress by the weevil has been made along certain wagon roads, rather than in the direction of prevailing winds, streams, or railroads. This point they illustrate by the road to St. Charles, Idaho, where the insect has gone 100 miles along the main road, across mountain ranges, regardless of prevailing winds, and far from railroads. In a later paper Reeves (1927*a*) remarks that there is no clear relation between the weevil travel and the prevailing winds. To this Sweetman (1929) adds that very little has been reported regarding the effects of wind on the alfalfa weevil and it is possible that air currents may aid the adults in flight but on the other hand may prove to be injurious to the larvae.

In the complicated conditions which govern the spread of the pest it is very difficult to say just how important any one of the factors may be. As conditions change, sometimes one, sometimes another, may appear to

be the most important. Unquestionably this leads to conflicting reports of results at times even when work is carefully done.

At the border of an infested region, it is difficult to determine what part of the spread is due to natural flight and crawling, and what part may be artificial. From our very limited experience it seems that the weevil could very easily and often be carried in fresh-cut hay to dairies and the like in the near vicinity of the border. It further seems certain that when beetles are numerous they might easily be carried considerable distances in clothing, etc. In other words, as an infested area extends, considerable farming and commercial intercourse may occur between infested and uninfested fields, which would offer the maximum opportunities for artificial spread.

ARTIFICIAL DISSEMINATION

Means of disseminating the alfalfa weevil has been a much debated subject, and many quarantine measures against the pest have at times been enacted which were intended to prevent or check its advance. There are many means by which it can be transported, and under some favorable conditions it can probably be carried long distances and remain alive for rather long periods. If this were not the case it is doubtful whether it would ever have been introduced into Utah from Europe. Of the many ways by which it can be carried, most are probably unfavorable to the beetle, and further if the pest should survive transportation it would be necessary for it to escape in the neighborhood of one of its hosts in order to become established. The weevil unquestionably has often been artificially carried far and wide, but the chances of its gaining a foothold are rather small, and since its introduction into Utah it has made only a few long jumps of this character. Evidence that the weevil is freely transported is given by the following statement, which is taken from the Weekly News Letter of the California State Department of Agriculture (1924):

> During the month of June [1924] many live alfalfa weevils, were taken from automobiles. As many as 140 live weevils were shaken from the camping equipment of a single car. In one case 40 live weevils were intercepted in a small quantity of green alfalfa hay which a camper had gathered in Nevada. Interceptions of from one to a dozen or more alfalfa weevils in a live condition are daily occurrences at the border stations.

Alfalfa meal has been suspected as a commodity which might be of importance in spreading the weevil. However, there seems to be little danger of this where alfalfa is milled under proper conditions. Dean (1932) reports that certain types of mills are fatal to the alfalfa weevil;

when the latter are passed through the entire milling process, it was demonstrated upon careful examination of the resultant product that the insects were entirely destroyed. Reeves, Hawley, *et al.* (1932) substantiate Dean's findings and further state that by intensive examinations of all parts of mill premises, it is established that few weevils even reach the premises. Of those found about the mill all were in such locations as to constitute little if any menace in recontamination of the meal prior to shipment. However, even this slight chance could readily be eliminated by the construction of screened runways between sacker and railway car. Any hazard from weevil-contaminated sacks could be prevented efficiently and economically by sterilization of the sacks before use. Thus the conditions are such that alfalfa meal is, or can readily be rendered, no more important in the spread of alfalfa weevil than any other class of merchandise, and may be moved during all months of the year with equal safety. In conclusion it is pointed out that there appears to be no reason, in the interest of preventing weevil spread, why alfalfa meal should be restricted more than other weevil-free merchandise.

In the examination of alfalfa mills Reeves (1930*b*) reports the finding of but 24 live weevils in one, and 20 live weevils in another, all of which were found in the receiving rooms and none in the finished product or the shipping rooms of the mills. This amounted to the finding of one weevil to each 5.8 hours of search in the first mill and to each 7.75 hours in the other and indicates the entire absence of the much discussed tendency of weevils to accumulate at mills.

Larrimer and Reeves (1929) reach the conclusion that the large number of weevils present in the growing crop diminishes with each step in the handling of the hay so that the accumulation on the premises of an alfalfa-meal mill, even at the end of the summer, is negligible; and the only source of contamination in the mills, generally speaking, is the hay which is being ground. They further state that in certain mills it was possible for weevils to pass through the machine alive but that this condition was easily remedied, so that meal could be delivered uninfested at the door of the freight car. It is also pointed out that cars which have been used for infested alfalfa hay, remain infested for an indefinite time thereafter, and that these cars, and not the alfalfa meal, constitute the real danger; and it is remarked that these cars are used more frequently for other commodities than for alfalfa meal.

Hawley (1932) found that after weevils have been in a haystack through the winter months it is difficult to find any of them alive in the spring and of course there would be little danger of contamination in alfalfa meal made of such hay.

There is apparently no danger of spreading the weevil in alfalfa-seed shipments. Titus (1910*a*) first called attention to this fact, and Parks (1913) substantiated his findings. Reeves, Miles, *et al.* (1916) state that live weevils do not occur in alfalfa seed, either before or after it is recleaned. Henderson (1919) also cites data which show conclusively that there is no danger of carrying the pest in alfalfa seed.

While neither alfalfa meal nor seed seem to be of importance in the spread of the weevil, alfalfa hay at times may play an important part in its distribution.

Titus (1909*b*) reports that where animals are being shipped from the country, for instance at the time of such events as a state fair, abundant opportunity may be given for the insect to pass to some other uninfested district or even out of the state. "The hauling of hay from one part of the state to the other, and the carrying of feed for horses, sheep, and stock, by persons driving through an infested region, will materially aid in the distribution of the insect." He states that this has been especially true of the weevil distribution in the Summit County region of Utah. In another paper he states:

> While the crop is being put up, weevils are often so numerous that men working in the fields are made decidedly uncomfortable by weevils crawling outside and inside their clothing, over their faces, and in their hair, and where the hay from the fields is being put in barns, one side of a barn may at times be almost covered with adults. Later in the winter or in the early spring, when the last of this hay is being fed out, the floor of the barn will often be swarming with beetles which have passed the winter in this well-protected place. (Titus, 1910*a*.)

However, the investigations of Hawley (1932), already mentioned, have shown that but a few of the weevils survive the winter out of doors in the stacks. He found that of the many weevils which collect around the bottom of the hay stacks, only a few were alive the following spring because of the wet and decomposed condition that obtains around the bottom of overwintering stacks. He further observes that in the upper part of the stacks the mortality in the hay samples examined ranged from 91 to 98 per cent and reports that weevils live readily for one month in baled hay, and a few may live for two months, but none can survive several months.

Reeves, Miles, *et al.* (1916) state:

> Another important consideration as to the occurrence of the weevils in new hay is that many people driving through the country in summer carry it for short distances as feed for their horses. The weevils may leave the hay as a result of the jar of travel, according to their habit; and that they do so is the more probable because no colonies have been found at any distance from the main territory, as would have happened if they were carried long distances by wagon. There is,

however, a constant stream of traffic over certain main roads, composed of sheepmen, peddlers, and others bent on business or social visits to other localities, near or remote. The carrying of weevils by these people, even if it be but for a mile or two, amounts in the aggregate to a systematic relaying of the species over through routes. There seems, in fact, to be a relation between the localities where alfalfa from infested fields is carried in this way and the country over which the weevils have spread most rapidly.

Again Reeves (1917) reports that nearly every case of the occurrence of the weevils in commerce has been traced to actual contact of the commodity with infested alfalfa hay. Weevils are found in hay hauled in wagons, in certain cars of potatoes, and in clothing worn upon trains and carried in trunks. In a later paper (Reeves, 1927*a*) he reports that the occurrence of the weevil upon farm produce can usually be traced to the handling of the latter in contact with freshly cut alfalfa. Again in 1930 he carried on investigations which showed that relatively few of the weevils which are so abundant in the fields ever reach the stack, and those which do so perish for the most part before the hay is removed from the stack, and that baling kills most of the rest (Reeves, 1930*a*).

From the studies of Reeves and Hawley, it appears that there is little danger of the weevil's being spread in alfalfa hay which has remained in the field throughout the winter.

Webster (1912) points out an interesting case in which hay was shipped from an infested territory into an uninfested area without the weevil's becoming established. He states that for a considerable time after the weevil became abundant about Salt Lake and Murray, hay was shipped from these points to Ely, Nevada. This occurred in the midst of the season, when it would seem impossible to transport hay from these points to its destination without carrying a greater or lesser number of the weevils. Notwithstanding this, years have gone by, and during the summer of 1911, two assistants examined the country about Ely most carefully without finding a single alfalfa weevil or any indication that it had ever existed there.

Potatoes and the alfalfa weevil are often associated together. This seems to be the result of farmers' handling their potatoes along with infested alfalfa. Thus Henderson (1919) states: "The only known means by which alfalfa weevil can be transported is in alfalfa hay or on objects contaminated only by alfalfa hay, particularly potatoes which have been brought to market in conveyances bedded with alfalfa hay." Reeves, Miles, *et al.* (1916) say that the occurrence of weevils in green alfalfa hay and new hay of the second crop is particularly important because potatoes which are to be shipped are often hauled to the car upon a bedding of it to prevent bruising and are sometimes covered with

it for protection from the sun. This hay when from infested districts, often contains weevils, which crawl from the alfalfa to the sacks and are loaded into the tight refrigerator car, in which they often remain until it reaches its destination. Although no colonies are known to have been started by this means, there is constant danger of it, which can be minimized by simply keeping the hay away from the potatoes. Weldon (1916) also points out the danger of the pest's gaining entrance to sacks of potatoes, and states that a number of weevils have been taken from potato cars in Montana. He suggested that before shipping, potatoes should be screened and transferred to clean sacks.

Titus (1910*a*) reports that many fruit orchards are partly surrounded by alfalfa and that migrating weevils from these often crawl into the fruit packages which are being shipped to other sections of the state or to other states. Weldon (1916) points out that emigrants moving from an alfalfa-weevil-infested state are apt to use hay, or other material containing alfalfa weevils, in packing goods or cars. Newton (1926*a*) states that the problem of the tourist and the transient laborer during the harvest season, and the movement of farm products, all represent just a part of the many artificial factors contributing to the dissemination of the pest.

Just what part the railroads have played in the spread of the weevil is a question. As there have been only a very few long jumps made by the insect it would appear that they have played only a minor role. Parks (1913) states that railway trains are particularly apt to carry the beetles during the time they are flying, but has thus far found no new areas of infestation that can be attributed to this or any other artificial agencies of dispersion. Titus (1910*a*) reports that it is not uncommon, during the flying season, to find weevils in cars on the railroad trains which are passing out of Salt Lake Valley into other valleys. Weevils flying against these trains cling there and may not drop off for several miles. If the locality where they leave the train is favorable for their hibernation or breeding, a small colony may easily be started. Weevils that get inside of cars may be carried for almost any distance. Twenty-seven were taken in the vestibule of one sleeping car on a train in Salt Lake County one day in July, 1910. Titus (1913) remarks that although many specimens of weevils have been carried out of the infested area by train, to that date no colonies were found that could be certainly attributed to this cause alone.

Reeves, Miles, *et al.* (1916) report that if railroad trains have carried the weevils, it has evidently been only for short distances. It is further stated that no connection can be traced between the railroads and the

actual spread of the alfalfa weevil; in fact, the advance of the weevils has been rather less rapid along some railroads than in certain regions remote from them. The weevils occur rarely in baggage, express, and freight cars, but somewhat more often in passenger cars and refrigerator cars containing potatoes which have been handled with fresh second-crop alfalfa hay. Their investigations have also shown that the transportation of the weevils on railroad trains and wagons is little affected by the flying of the species. It seemed reasonable at an early period of the investigation to believe that a beetle which flies abroad in the summer would alight upon various commodities and vehicles and be carried for great distances, but such is not the fact. Weevils are rarely found on trains or wagons except in cases where new hay is involved.

Reeves (1930*a*) states that over 2,000 cars are used each year for the shipping of infested hay, and that these cars are dispersed rapidly into every corner of the United States. He carried on investigations which showed that 15 per cent of the weevils remained alive in the car during a 5-day trip, and 40 per cent of them during a 3-day trip, and points out that these car histories are ominous. Again Reeves, Hawley, *et al.* (1932), in their study on the alfalfa-meal quarantine in relation to the spread of the weevil, state that from the point of view of preventing future spread of the pest it is their opinion that the movement of empty hay cars infested with living weevils constitutes a far greater menace than any other factor which has come under their study, and that railway cars assuredly free from weevils cannot be had at the present time. Larrimer and Reeves (1929) substantiate the above and in their paper report that freight cars which have been used for infested alfalfa hay remain infested for an indefinite time.

H. S. Smith (1917) points out that during the first 13 years the pest had existed in America up to 1917, not a single long jump had occurred in its distribution. Even in the infested states he reports that the pest had not traveled more rapidly along the railroads than elsewhere, although the adult beetles had been taken countless times from Pullman and freight cars.

On the other hand, there is some almost positive proof that railroads have played a role in the spread of the weevil. Certainly it seems that it must have been first carried to Utah by train from the seaboard. Further, the infestation in middle California was probably started by weevils brought in by the railroad.

There is some evidence that the weevil is carried by water, but this means of spread seems to be of but little importance. Titus (1909*b*) reports that weevils fall into irrigation ditches and are swept onward,

and at times into a field, where they may secure lodgment on leaves or stems of the plants. Once they obtain solid footing they go on until they reach a field where food plants are present or until night drives them to shelter. Webster (1912) states that the weevil appears to float about freely on the surface of water, and is doubtless carried long distances down stream by the current. This is true in the case of irrigating ditches and canals. List and Wakeland (1919), working in Colorado, showed that the adult weevils are able to live in water for fairly long periods, and point out the apparent danger of their being spread in irrigation water to uninfested fields. However, in the following year, Wakeland (1920) reports that scouting disclosed the fact that the weevil had in a year's time, spread over such a large territory by flying that its dissemination by means of irrigation water is relatively unimportant as far as adjacent territory in Colorado is concerned. Newton (1926*a*) remarks that even though it has been demonstrated that irrigation waters carry the insect down stream, the most rapid spread has often been up stream. One particular case in mind is that of a number of fields which have not become infested even though they are continually irrigated from a ditch that flows through an infested area on a mesa, or tableland, above. Reeves (1927*b*) also points out that the weevil is known to be carried by irrigation canals, and presumably by rivers.

NATURAL ENEMIES

In Asia and Europe there are a number of natural enemies which attack the alfalfa weevil. These consist of two main groups: animals and fungi. Of the animals, insects are the most important because they are more abundant in species and numbers and more specific in their host requirements. Birds and certain small insectivorous mammals also play a part in the reduction of the numbers of the weevils in the fields. Among the fungi which subsist on this, and other insects, are the entomophthorales which may attack the different stages of the weevil.

Certain of the insect parasites have been introduced into the United States by the United States Department of Agriculture Bureau of Entomology and have become established in the infested alfalfa fields of the Great Basin.

It does not seem desirable to enter into a lengthy discussion of all of these natural enemies here, especially of those not present in this country, but a brief summary of the latter is given, with a fuller treatment of those established in this country.

Insects which actually devour the larvae and adults of the alfalfa weevil are numerous, but because they are usually general feeders and

do not confine their feeding to this particular pest, their effectiveness in reducing the numbers of the weevil is of little concern. Therefore, the predators have not been carefully studied and the published reports concerning them are meager, both in this country and in Europe. The following list will serve to give some idea of the groups of predators that might be expected to destroy the weevil wherever it occurs.

MITES

The ventricose mite, *Pediculoides ventricosus* (Newport), has been observed to destroy the eggs of the alfalfa weevil in alfalfa fields in Utah and specimens were even introduced into the fields, although the mite was later found to occur in the region (Webster, 1912). This noxious mite is almost cosmopolitan in distribution. It also attacks the miniature stages of various hymenopterous parasites, other insects, and even man, and is therefore hardly to be considered as an adjunct of any importance in the control of the alfalfa weevil.

The red predacious mite, *Erythraeus arvensis* Banks, has been observed feeding on the eggs of the alfalfa weevil in Utah (Webster, 1912).

INSECT PREDATORS

Tiger Beetles, Family Cicindelidae.—The adults of the imperfect tiger beetle, *Cicindela imperfecta* Lec., have been observed feeding on the alfalfa weevil larvae in Utah (Webster, 1912). This beetle also occurs in Texas, Utah, Nevada, California, Oregon, and Washington (Leng, 1920).

Ladybird Beetles, Family Coccinellidae.—The convergent ladybird beetle, *Hippodamia convergens* Guerin, has been observed to attack the alfalfa weevil. In Utah the larvae of the ladybird have been recorded as feeding on the larvae of the weevil (Webster, 1912) and in California we have seen the adult ladybird fiercely attack and devour the young larvae of the alfalfa weevil. How much good they do in destroying the pest is not known. This beetle occurs throughout the entire United States and is especially abundant in the western states.

A related species, *Hippodamia sinuata* Muls. var. *spuria* Lec., has also been recorded as feeding in the larval stage on the larvae of the weevil (Webster, 1912). This ladybird beetle occurs throughout the Rocky Mountain region and the western states.

The nine-spotted ladybird, *Coccinella 9-notata* Hbst., has habits similar to the other two species; the larvae and also the adults attacking the larvae of the weevil (Webster, 1912). It occurs throughout much of the United States, but does not appear to be numerous in any large area.

Soft-winged Flower Beetles, Family Melyridae.—The two-spotted collops, *Collops bipunctatus* Say, feeds in the adult stage on the alfalfa weevil in Utah (Webster, 1912). It ranges from Kansas to California.

Darkling Ground Beetles, Family Tenebrionidae.—Adults of the darkling ground beetle, *Eleodes sulcipennis* Mann., are recorded by Webster (1912) as feeding on the larvae of the alfalfa weevil in Utah. The insect is also known to occur in Idaho, northern California, Oregon, and Vancouver.

INSECT PARASITES

Among the most important natural enemies of the alfalfa weevil are the insect parasites, of which there are a number attacking the eggs, larvae, prepupae, and pupae. These parasites are for the most part small or minute, active, winged insects of the order Hymenoptera. They lay their eggs in or on the host and the larvae feed inside or on the exterior and eventually completely destroy the particular stage of the weevil attacked. All of the known parasites of the alfalfa weevil are of Old World origin. Of the many studied in Europe and subsequently introduced into this country, only two species have been established in the alfalfa-weevil-infested fields of the Great Basin and in Nevada.

Usually much more is expected and claimed of the larval parasites than can be gained in a practical way. The alfalfa weevil is greatly affected by climatic conditions, as is shown elsewhere in this paper, and the sudden reduction of the pest because of unfavorable weather is often wrongly ascribed to the work of parasites, the activities of which are difficult to observe and the actual efficacy of which is not accurately known. Concerning the efficacy of *Bathyplectes curculionis* on weevil increase and control, Chamberlin (1924) makes this statement:

> Before parasites become numerous, it was observed that for several years after the weevil is first noticed in any locality it increases at a tremendous rate, but that after the third or fourth year the insect is apparently taken under conrol by natural influences and ceases to increase. According to egg-laying records of weevils kept in the laboratory, the potential annual increase is not far from 400 to 1. It follows that natural control depends upon the removal in one way or another of about 99.8 per cent of the females of each generation. Unfortunately, before this condition is attained, the weevils are numerous enough to produce destructive numbers of larvae.
>
> These natural controlling factors include winter killing and summer killing, and it is largely because of the latter that the effect of this parasite (*Bathyplectes* [*curculionis*]) upon the reproduction of the weevil is greatly reduced. The summer killing in large part takes place at the time of the cutting of the first crop, when larvae are exposed to the hot dust, and in hot and dry weather about 90 per cent are removed in this way. This mortality is independent of the parasites and takes place just as surely without as with them, and their work is largely wasted upon

victims that would not produce offspring in any event. This goes far to explain why *Bathyplectes* can destroy 90 per cent of the larvae year after year without causing any marked decrease in the numbers of the pest. Considering this fact, together with the continued feeding of parasitized larvae and the recent weather conditions, there may still be doubt, in spite of the great numbers of existing parasites, that these have caused the improvement in the crop which has generally

TABLE 8

LIST OF HYMENOPTEROUS PARASITES ARRANGED ACCORDING TO THE VARIOUS STAGES OF THE HOST*

Reared from eggs of the alfalfa weevil	Reared from larvae of the alfalfa weevil
Anaphoidea luna Gir. (*Anaphes* sp.)	*Adelognathus* sp.
Eupelminus excavatus (Dalm.)	*Bathyplectes corvina* (Thoms.)
Peridesmia phytonomi Gahan ("Pteromalid A")	*Bathyplectes curculionis* (Thoms.)
Spintherus sp. ("Pteromalid B")	*Bathyplectes tristis* (Grav.)
	Stenocryptus nigriventris Thoms.
	Tetrastichus sp.
	Tetrastichus incertus (Ratz.)

Reared from cocoons—prepupae and pupae—of the alfalfa weevil	Reared from alfalfa-weevil material; stage of host unknown
Aenoplegimorpha micator (Grav.)	*Eutelus* sp.
Dibrachoides dynastes (Förster)	*Eulophus* sp.; may be a secondary
Hemiteles graculus (Grav.)	
Hemiteles hemipterus (Fab.) (secondary?)	
Necremnus leucarthros (Nees)	
Pimpla maculator (Fab.)	
Spilocryptus pumilus Kreich.	

* A single dipterous parasite, *Tachina impotens* Rondani, was reared from a larva of the alfalfa weevil in France (Thompson, 1920). The various hymenopterous parasites are more fully discussed in their proper families in the following pages.

been credited to them. When circumstances favor development of the weevils rather than the alfalfa, and the insect is permitted by climatic conditions to develop its attack as formerly, the value of the parasites will be subjected to a true test. *Until then they must be counted a potential safeguard to be studied with a view to increasing their usefulness, while other means are relied upon to protect the crop.*

In discussing the alfalfa weevil with reference to its environment, Reeves and Hamlin (1931*a*), make this significant statement concerning the effects of parasitism on the control of the pest: "We dealt with such anomalies as a parasitism of 99 per cent which still failed to control the host; and a host with an enormous rate of multiplication whose numbers were still apparently self-limited after the first few years in a given locality."

Although ten species of parasites of the alfalfa weevil were liberated in Utah (Reeves, 1927*a*), only two have been established in the Great Basin. It is expected, however, that others might be acclimated in the newly infested districts of California, particularly parasites of the eggs and larvae of the weevil. As a matter of fact some of these new parasites are already being introduced through a coöperative project between the California Agricultural Experiment Station and the United States Department of Agriculture Bureau of Entomology. Because of this new interest in the parasites, we are listing all of the known species observed in the Old World, together with such available information as may be useful to those concerned with the alfalfa weevil in California and elsewhere.

Adelognathus sp., Family Ichneumonidae.

This insect is listed as a parasite on the larvae of the alfalfa weevil in Poland by Krasucki (1925).

Aenoplegimorpha micator (Gravenhorst), Family Ichneumonidae; (Chamberlin, 1924*a*).

Ichneumon micator Gravenhorst (1807), (Dalla Torre, 1891).
Hemiteles micator Gravenhorst (1829), (Dalla Torre, 1891).
Aenoplegimorpha phytonomi Viereck (1912), (Cushman, 1922).

This parasite is listed as occurring throughout Europe. It was introduced into and established in Utah, but is not important as a parasite of the prepupae and pupae of the alfalfa weevil. Chamberlin (1924*a*, 1924*b*). A single specimen was reared from the cocoon within the cocoon of the alfalfa weevil taken at Hoytsville, Utah, 1911, Webster (1912), and was described as a new species, *Aenoplegimorpha phytonomi* by Viereck (1912). This proved to be identical with the European *A. micator* (Grav.) (Cushman, 1922).

Bathyplectes corvina (Thomson), Family Ichneumonidae; (Chamberlin, 1924*a*).

Canidia corvina Thomson (1887), (Dalla Torre, 1891).
Canidiella corvina (Thomson), (Dalla Torre, 1891).

Bathyplectes corvina is parasitic on the larvae of the alfalfa weevil. This species, which is similar in habits to, and coextensive with, *B. curculionis* (Thomson), is found practically throughout the range of the alfalfa weevil in Europe, having been noted as *Canidiella curculionis* (Thoms.) in Kuban, Russia, by Grossheim (1913); in Sweden and Germany by European entomologists (Dalla Torre, 1891); and in southern Europe by Chamberlin (1924*b*).

According to Chamberlin (1924*b*) it is one of the most promising

parasites of the alfalfa weevil in Europe and may be the dominant one in some localities, as at Hyères, France, in 1922 and 1923.

It normally pupates in the fall and passes the winter either in the pupal or in the adult stage within a cocoon and issues in the spring. It has but one generation a year. It is difficult to handle in confinement and was never established in this country.

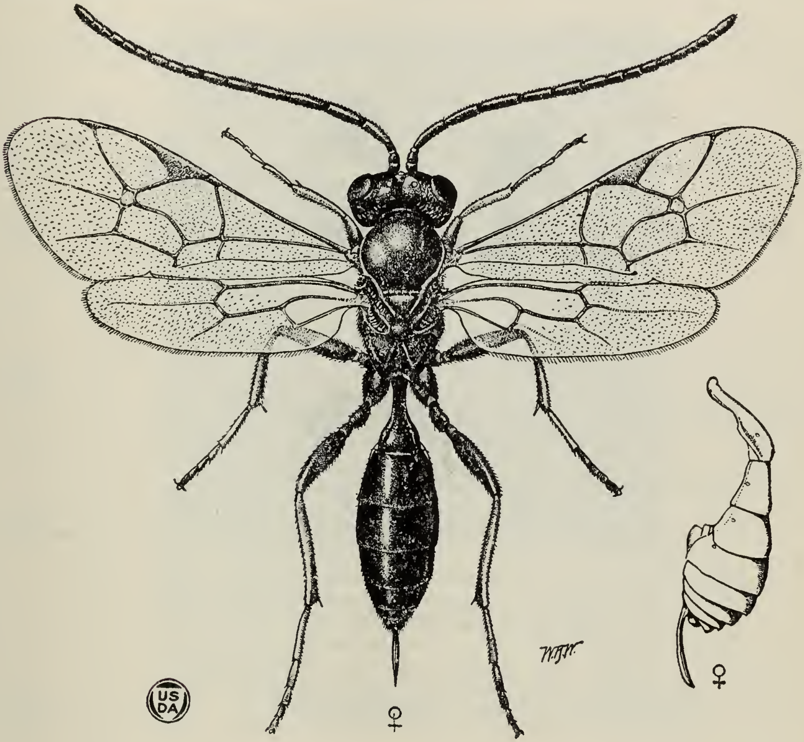

Fig. 13.—*Bathyplectes curculionis* (Thomson), an introduced parasite of the larva of the alfalfa weevil: adult female with lateral view of the abdomen at right. (After Webster, U. S. Department of Agriculture, Bureau of Entomology, 1912.)

Bathyplectes curculionis (Thomson), Family Ichneumonidae; (Chamberlin, 1924*a*).

Canidia curculionis Thomson (1887), (Dalla Torre, 1891).
C. subcincta Holmgren (1858), (Dalla Torre, 1891).
Canidiella curculionis Thomson, (Dalla Torre, 1891).

This is an internal parasite (figs. 13 and 14) of the larvae of the alfalfa weevil. It is the only important parasite of the alfalfa weevil established in this country and has had a rather remarkable development in the Great Basin.

Adults issue from overwintering cocoons of the host in spring and oviposit in larvae of the host. The development from egg to full-grown larvae requires about two weeks. Full-grown larvae issue from the prepupal larvae of the weevil after the cocoons of the latter are spun and make their own cocoons within that of the alfalfa weevil. Adults issue from the cocoons in about two weeks and oviposit in weevil pre-

Fig. 14.—*Bathyplectes curculionis* (Thomson), the parasite of the larva of the alfalfa weevil, and cocoons. The latter are chocolate brown with a pale band. They occur in the cocoons of the weevil. This parasite has been recently introduced into California. (Courtesy California State Department of Agriculture.)

pupal larvae of the same generation; at this time the weevil larvae are most abundant. The cocoons of the second generation parasites are usually darker and thicker than those of the first generation, being from a medium-brown to chocolate-brown color with a distinct whitish band around the middle. Most of the second-generation parasites remain in their cocoons as prepupal larvae until the next spring, when they pupate and issue as adults (Chamberlin, 1924*a*).

It is widely distributed in the Old World, being recorded in Boreal and central Europe by Dalla Torre (1891), in Germany, Switzerland, France, Italy, and Sicily, by Martelli (1911); in Kuban, southern Russia, by Grossheim (1913); in Tunisia, northern Africa, by Chamberlin (1926); and in Turkestan, Asia, by Dvornitchenko (1917).

After a study of the parasite in southern Europe, shipments of cocoons and parasitized larvae of the alfalfa weevil were made to America by W. F. Fiske in 1911, H. S. Smith in 1912, and W. R. Thompson in 1912 and 1913. Those sent over by Thompson were mostly from Switzerland. The material was shipped in screen cans in cold storage.

TABLE 9

SUMMARY OF THE ECONOMIC RECORD OF *Bathyplectes curculionis* IN THE UNITED STATES

State	Year	Introduction, and percentage of parasitism found	Authority
Utah	1911–1914	Introduced from Europe	Chamberlin (1926)
	1914	Present in fields—scarce	
	1916	From 2 per cent to 30 per cent	
	1919–1920	Often exceeded 90 per cent	
	1924	From 29.9 per cent to 84.5 per cent	
	1925	From 8 per cent to 97.3 per cent	
Idaho	1919	Abundant at Paris, Idaho; spread naturally from Utah	Chamberlin (1926)
	1920	Present at Ashton	
	1924	Reached 25 per cent	Idaho Agr. Exp. Sta. (1925)
	1925	Reached 50 per cent	Idaho Agr. Exp. Sta. (1926)
Colorado	1918	Introduced from Utah	Chamberlin (1924*a*)
	1919	Additional introductions	Newton (1921)
	1920	From 1 per cent to 30 per cent	
	1922	About 50 per cent	Newton (1923)
	1923	As high as 60 per cent	Newton (1924)
	1924	From 25 per cent to 89 per cent	Newton (1925)
	1925	From 40 per cent to 60 per cent	Newton (1926*a*)
	1926	During 8 years the parasite spread at the rate of 6 miles per year	Newton (1926*b*)
Nevada	1921	Introduced from Utah	Chamberlin (1924*a*)
	1922	Introduced from Utah	Doten (1928)
	1925	Parasite throughout weevil-infested area	Snow (1925)
California	1933	First introduced into central part	

Only about 50 per cent of the primary parasites subsequently issued and secondary parasites issued in confinement from between 24 and 65 per cent of the cocoons.

In 1911, 40 adults of this parasite were liberated in field cages in the weevil-infested alfalfa fields near Sandy, Utah, and later the cages were opened to allow them to escape into the fields. In 1912, 48 males and 121 females were liberated directly in the fields. In 1913 and 1914, 1,335 parasites were liberated in the alfalfa fields at Ogden, Kaysville, and Salt Lake City, Utah—all of which were from the 1913 importations. Other liberations followed in 1914, bringing the total number liberated

to 1,544, a rather small number considering the rapid subsequent spread of the insect. In view of the difficulties and failures in establishing other parasites of the alfalfa weevil in Utah, the colonization of this one was easy and the natural increase and diffusion was rapid. In 1914, the first field recovery of small numbers of adults was made near Sandy, where the first liberations were made. It was also found in considerable numbers at Murray and Salt Lake City. By 1916 it had dispersed along the eastern side of the Salt Lake Valley to a distance of 8 or more miles and an examination of 3,000 weevil cocoons showed a parasitism of 22.5 per cent. It was also found in Weber Valley, 30 miles east of Salt Lake City, where the parasitism ranged from 2 per cent to 30 per cent, and at Kaysville and Ogden. In 1917 the parasite had reached Praco, 35 miles from Salt Lake City, and by 1918 it had reached Brigham City, 50 miles distant. In 1919 the parasite spread as far as Salina, Utah, 120 miles south of Salt Lake City, and to Paris, Idaho, 95 miles north. By 1920 it was found at a maximum distance of about 230 miles from Salt Lake City and occurred in Idaho, Wyoming, and in eastern, western, and southern Utah. It spread 196 miles from Ogden, Utah, to Ashton, Idaho, in six years during the period from 1914 to 1920, and 230 miles in eight years, which shows the great power of flight and the very rapid dispersal of the parasite. No definite additional recent figures on this matter are available. See table 9.

Observations by various workers concerning the increase, spread, and effectiveness of *Bathyplectes curculionis* are given below:

The parasite, *Bathyplectes curculionis,* has increased in numbers until it now [1924] actually swarms in the infested fields of Utah and destroys over 90 per cent of the weevil larvae in the older sections, much surpassing its effectiveness in any of the localities studied in Europe at the time of the importations, where the highest local average of parasitism by all species of parasites which attack the larvae was 12.5 per cent. [Chamberlin, 1924*a.*]

Bathyplectes does not appear present in the fields to parasitize the larvae heavily at all periods of the year, a fact which leads one to suppose that its work might well be supplemented by a many-brooded larval parasite, which would work late into the season. [Chamberlin, 1926.]

It is believed that this parasite must destroy enormous numbers of the weevils, but the effect is so long delayed (until the breeding season of the following year), and the rate of increase of the weevil is so rapid, that the practical value of this parasitism is not yet certain. Intermittent and unforseeable control of the pest might do as much harm as good; it would still be necessary for the farmer to carry the overhead expense of spraying for the weevil, and he would often be deluded by a false feeling of security into neglecting preparations for weevil control, and consequently lose his crop. [Reeves, 1927*b.*]

In the course of the fiscal year it became evident that the introduction of the parasites of the alfalfa weevil by the Station in 1922 had been effective in finally bringing about a reduction in the destructiveness of the pest; but not as yet to the extent of making spraying or dusting of the fields unnecessary. [Doten, 1929.]

It has been discovered that an overwhelming percentage of parasitism may be completely offset in its economic effect by weather conditions. [Reeves, 1930.]

Authorities agree that the *Bathyplectes* parasite is often abundant in the infested fields and reduces the numbers of the weevil larvae materially, but it does not appear to be a real economic factor in the actual control of the pest.

This parasite was introduced into the alfalfa-infested fields in California by the United States Department of Agriculture Bureau of Entomology during the summer of 1933.

Secondary parasites of *Bathyplectes* spp. in Europe are given by Chamberlin (1924*a*, 1924*b*) as: *Mesochorus nigripes* Ratz., *Gelis stevenii* (Grav.), *Dibrachys boucheanus* Ratz., and *Eupteromalus* sp. The first of these secondaries, *Mesochorus nigripes* Ratzeburg (1852), has also been listed as a parasite of the larvae of the alfalfa weevil in Poland by Krasucki (1925).

Bathyplectes tristis (Gravenhorst), Family Ichneumonidae; (Chamberlin, 1924*a*).

Campoplex tristis Gravenhorst (1829), (Dalla Torre, 1891).
Limneria tristis Marshall (1872), (Dalla Torre, 1891).
Canidia tristis Brischke (1880), (Dalla Torre, 1891).
Canidiella tristis Gravenhorst, (Dalla Torre, 1891).

This is an internal parasite of the larvae of the alfalfa weevil and the clover leaf weevil. It is rather scarce and has probably but one generation a year.

It has been recorded in Great Britain and Germany without reference to hosts by Dalla Torre (1891) and in southern Europe, on the abovementioned alfalfa-weevil hosts, by Chamberlin (1924*b*).

Hemiteles graculus (Gravenhorst), Family Ichneumonidae; (Chamberlin, 1924*a*).

Bassus graculus Gravenhorst (1829), (Dalla Torre, 1891).

Hemiteles graculus is an unimportant parasite of the alfalfa weevil and the only member of the Cryptinae found in any considerable numbers in Italy (Chamberlin, 1924*b*). Dalla Torre (1891) also lists it from Great Britain without reference to hosts. It apparently oviposits in the prepupae only.

Hemiteles (Aptesis) hemipterus (Fabr.), Family Ichneumonidae; (Cushman, 1927).

Ichneumon hemipterus Fabricius (1793), (Dalla Torre, 1891).
Hemiteles insignipennis Schmiedeknecht (1905), (Cushman, 1927).

This parasite has been reared from the cocoons of the alfalfa weevil collected in southern Europe and has been recorded from Germany by Schmiedeknecht (1905). It has also been reared as a hyperparasite of *Microgaster tibialis* Nees and *Eulimneria crassifemur* (Thomson), primary parasites of the European corn borer, *Pyrausta nubilalis* Hbn. (Cushman, 1927).

Pimpla maculator (Fabricius), Family Ichneumonidae; (Escherich, 1931).

Itoplectis maculator (Fab.), (Chamberlin, 1924*a*).
Ichneumon maculator Fabricius (1775), (Dalla Torre, 1891).
Pimpla maculator Gravenhorst (1818), (Dalla Torre, 1891).

This is an internal parasite of the prepupae and pupae of *Phytonomus* spp. as reported by Chamberlin (1924*b*) and also noted on the immature stages of many moths and other insects in Europe. The adults oviposit through the cocoons of the hosts.

This species is recorded as occurring throughout the continent of Europe by Dalla Torre (1891), who lists as hosts twelve species of Lepidoptera, one species of Hymenoptera, and one undetermined Arachnida. Escherich (1931) also lists two species of Lepidoptera, one of which is included in those by Dalla Torre.

It is recorded as a parasite of the alfalfa weevil in southern Europe—France and Italy—by Chamberlin (1924*b*), in France by Picard (1914*a*), and in Russia by Grossheim (1913).

A secondary pteromalid parasite, *Catolaccus ater* Ratz., is thought to attack *Pimpla maculator* (Chamberlin, 1924*b*).

Spilocryptus pumilus Kreichbaumer (1899), Family Ichneumonidae; (Chamberlin, 1924*a*; Dalla Torre, 1891).

This parasite, which is apparently of little importance, was noted on the prepupae and pupae of the alfalfa weevil in Italy by Chamberlin (1924*a*) and was also recorded in Tyrol by Dalla Torre (1891). The life cycle is 17 days.

Stenocryptus nigriventris Thomson (1873), Family Ichneumonidae; (Krasucki, 1925).

Pammachus nigriventris (Thomson), (Dalla Torre, 1891).

This larval parasite of the alfalfa weevil was noted in Poland by Krasucki (1925) and listed in Boreal and central Europe by Dalla Torre (1891).

Necremnus leucarthros (Nees), Family Eulophidae; (Chamberlin, 1924*b*).

Eulophus leucarthrus Nees ab Esenbeck (1834), Dalla Torre, 1898).
Necremnus leucarthros Thomson (1878), (Dalla Torre, 1898).

This is an external parasite on the prepupae of the alfalfa weevil with habits similar to those of *Dibrachoides dynastes* (Förster). The eggs are laid externally on the host, as many as 41 being deposited upon a single prepupa in the laboratory. Only a few of these mature, but 18 adults have been reared from a single prepupa of the alfalfa weevil. It is one of the most promising weevil parasites in Europe, although it is found only in fair numbers there. It was collected in France and Italy by Chamberlin (1924*b*, 1925*b*) and reported in Germany by Nees (1834) and in Sweden by Dalla Torre (1898).

This parasite has also been observed to attack the immature stages of the chrysomelid beetle, *Lema cyanella* Linn., in Moravia (Ruschka and Fulmek, 1915; Chamberlin, 1925*b*).

Eulophus sp., Family Eulophidae.

Such an undetermined species is recorded as a parasite of the alfalfa weevil by Martelli (1911).

Eupelminus excavatus (Dalman), Family Eupelmidae; (Chamberlin, 1924*a*).

Eupelmus excavatus Dalman (1820), (Dalla Torre, 1898).

This is an external feeder on the eggs of the alfalfa weevil and the clover leaf weevil. Normally the larvae estivate in the stems of alfalfa plants and the adults issue in autumn. It is recorded by Dalla Torre (1898) in Great Britain and Sweden, and by Chamberlin (1924*a*, 1924*b*) in France, Italy, and Sicily.

Although introduced into Utah in 1913, this parasite apparently never became established there.

Anaphoidea luna Girault (1914), Family Mymaridae.

Anaphes sp.

This is a minute egg parasite (fig. 15) of the alfalfa weevil which is known to occur in France, Italy (Silvestri, 1915), and Sicily (Chamberlin, 1924*a*), where it also parasitizes the eggs of the clover leaf weevil, *Phytonomus punctatus* (Fabr.). This insect is particularly effective in destroying the eggs of the weevils deposited in dry stems.

According to Chamberlin (1924*b*) it places two eggs in each of the eggs of the clover leaf weevil and one in each of the eggs of the alfalfa weevil, which are smaller than those of the clover leaf weevil. It appears

to be somewhat restricted in its range in southern Europe. Although introduced into Utah in 1911, 1912, and 1913, it was not established in that state. (Chamberlin, 1924*a*, 1924*b*).

This parasite was introduced into California from southern Europe by the United States Department of Agriculture Bureau of Entomology, and the California Agricultural Experiment Station in the summer of 1933.

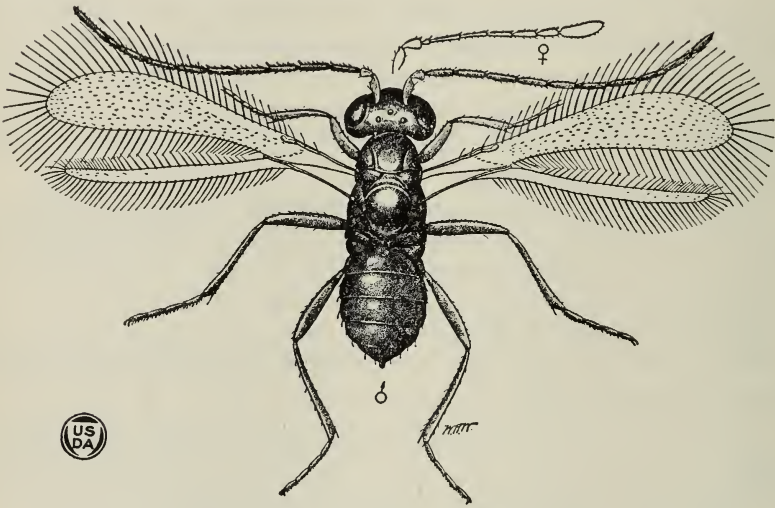

Fig. 15.—*Anaphoidea luna* Girault, a minute mymarid egg parasite of the alfalfa weevil: adult male; antenna of female above and to the right. This parasite was recently introduced into California. (After Webster, U. S. Department of Agriculture, Bureau of Entomology, 1912.)

Dibrachoides dynastes (Förster), Family Pteromalidae; (Chamberlin, 1924*a*).

Pteromalus dynastes Förster (1841), (Dalla Torre, 1898).

This is a small dull metallic-green and brownish parasite, 3 mm long. It is an external feeder on the prepupae and the pupae of the alfalfa weevil, and, according to Chamberlin (1924*a*), probably the most important parasite on these stages of the weevil in Europe. Three or four eggs are laid on the host and from one to as many adults may emerge from a single host. The prepupal stage of the weevil is preferred to the pupal. It hibernates as an adult. (H. D. Smith, 1930.)

This parasite is recorded in Germany by Förster (1841), in southern Russia by Grossheim (1913) and Kurdjumov (1913), and in France and Italy by Chamberlin (1924*a*, 1924*b*) and H. D. Smith (1930). It was introduced into California during the summer of 1933 by the United States

Department of Agriculture Bureau of Entomology and the California Agricultural Experiment Station.

In Europe a secondary parasite, a eulophid, *Pleurotropis* sp., attacks the pupae of this primary parasite.

This primary parasite was introduced into and artificially colonized in Utah in 1911 (H. D. Smith, 1930) and was found on the lesser clover leaf weevil, *Phytonomus nigrirostris* (Fab.) in Washington by Rockwood (1920) in 1920. Apparently it is of little consequence as yet in this country.

Eutelus sp., Family Pteromalidae.

This undetermined species is listed as a parasite of the alfalfa weevil in Italy by Martelli (1911).

Peridesmia phytonomi Gahan (1923), Family Pteromalidae; (Chamberlin, 1924*b*).

The larvae feed externally upon the eggs of the alfalfa weevil. This parasite is thought to be the most important and promising of the European parasites of the alfalfa weevil. It may be found feeding on egg masses in either green or dry stems of alfalfa. When in the latter they usually are preying on the eggs of the clover leaf weevil. In southern Europe the larvae are found feeding on egg masses in the fields from January to July, according to the locality. The highest parasitism of the weevil by this parasite was noted at Hyères, France, where it ranged from 10 per cent to 30 per cent. Concerning its climatic range Chamberlin (1924*b*) states:

> This parasite occurs in the most southerly point in French Riviera where frost rarely occurs and where the alfalfa grows practically throughout the year and also in Higher Savoy, altitude 2,500 feet, which has short summers and long winters and is one of the highest and coldest sections in France where alfalfa can be grown.

This parasite was introduced into California during the summer of 1933 by the United States Department of Agriculture Bureau of Entomology and the California Agricultural Experiment Station.

Spintherus sp., Family Pteromalidae ("Pteromalid B"); (Chamberlin, 1924*a*, 1924*b*).

An external egg parasite of the alfalfa weevil, this species, according to Chamberlin (1924*b*), is the most dominant egg parasite in the higher and colder regions of France and one of the most promising alfalfa-weevil parasites in Europe. It also occurs in the warmer lowlands of Sicily, showing an adaptation to wide climatic range. Its habits are similar to those of *Peridesmia phytonomi* Gahan.

Another member of this family designated as "Pteromalid A" is an external egg parasite on the alfalfa weevil in southern Europe, according to Webster (1912) and Chamberlin (1924*a*).

Tetrastichus incertus (Ratzeburg), Family Tetrastichidae; (Chamberlin, 1924*b*).

Eulophus incertus Ratzeburg (1844), (Dalla Torre, 1898).

This is an internal parasite of the larvae and prepupae of the alfalfa weevil. Oviposition occurs in the larvae, which turn yellow, pink, and finally reddish brown, and become plump in form. From 6 to 17 larvae of the parasite may occur within each larva of the weevil. It is one of the most promising parasites and exceeded the parasitism of any other alfalfa-weevil parasite in Europe, the effectiveness ranging from 54.6 per cent to 85.8 per cent, with an average of 71.2 per cent, in Italy. It is known to occur in Italy, France, Switzerland (Chamberlin, 1925*a*), and Germany (Dalla Torre, 1898).

A secondary, *Eupelmus atropurpureus* Dalman (1820), was reared from a single prepupa of the alfalfa weevil. (Chamberlin, 1925*a*.)

Tetrastichus sp., Family Tetrastichidae.

This undetermined species is recorded as an internal parasite of the larvae of the alfalfa weevil in southern Russia by Grossheim (1913). It may prove to be *T. incertus* (Ratz.).

ENTOMOPHTHORALES, OR FUNGUS PARASITES

Among the plants are certain fungi, which because they are mostly parasitic on insects, are known as entomogenous fungi. They cause epizoötics of larvae and adults of insects and at times are most effective in destroying great numbers of noxious species. In arid and semiarid regions, they appear to be abundant and beneficial only in wet seasons in spring or early summer. Wherever moisture is present, as along streams and irrigation ditches, these fungi may remain effective throughout much of the summer and fall. Infected insects, after death, are usually enveloped in a loose, white cotton-like growth of fungus mycelium, which serves as an indication of the presence of the fungi. Several species have been recorded as attacking the alfalfa weevil, clover leaf weevil, and other insects in Europe and in this country, but they are of little economic importance in reducing the weevil populations in the alfalfa fields.

The recorded species follow:

Entomophthora phytonomi Arthur.—This fungus has been reported as attacking the larvae of the alfalfa weevil in Denmark by Lind, Ros-

trup, and Kølpin Ravn (1917) and the larvae of the alfalfa weevil and the clover leaf weevil in France by Picard (1914*a*). The same species, listed as *Empusa sphaerosperma* Fresen [*Entomophthora sphaerosperma* (Fresen)] (Picard, 1914*b*), is credited with destroying from 38 per cent to 44.5 per cent of the alfalfa weevil in some localities in Utah in August, 1911, by Webster (1912).

Entomophthora (*Tarichium*) *punctata* Garbowski.—This is described as a new fungus, parasitic on the alfalfa weevil in the Poznań Province, Poland, by Garbowski (1927).

Sporotrichum globuliferum Spegazzini.—This species appears to be the most important fungus parasite of adult alfalfa and related weevils in this country. It also attacks the adults of the chinch bug and other insects. This fungus is most abundant in the spring and kills many of the hibernating weevils which are on the ground at that time. Rockwood (1916) first noted it attacking the alfalfa weevil near Salt Lake City, Utah, on March 14, 1914, and found it to be in greatest abundance from April 21 to 29, when a dead weevil was to be found under almost every alfalfa plant. After the cessation of the spring rains the fungus was restricted to fields copiously irrigated, where it persisted generally until July and in one field until September 10. In spite of its occasional abundance it is of little or no importance in the control of the alfalfa weevil.

BIRDS

Many species of birds observed feeding on the alfalfa weevil in North America have been listed by Webster (1912), Beal (1913, 1914), Kalmbach (1914), and McAtee (1921). It is remarkable that so many birds have taken advantage of this new food. Among the more important bird enemies may be listed the following:

- Brewer's blackbird, *Euphagus cyanocephalus* (Wagler): among the most effective bird destroyers.
- English sparrow, *Passer domesticus domesticus* (Linn.): the most effective of the birds as a destroyer of the alfalfa weevil in the Great Basin.
- Killdeer, *Oxyechus vociferus* (Linn.): a very effective destroyer of the weevil.
- Valley quail, *Lophortyx californica vallicola* (Ridgway): an effective enemy of the weevil.
- Western chipping sparrow, *Spizella passerina arizonae* Coues: the alfalfa weevil forms four-fifths of its food during months of weevil abundance.
- Western lark sparrow, *Chondestes grammacus strigatus* Swainson: an important feeder on the weevil in the spring months.
- Western meadowlark, *Stunella neglecta* Audubon destroys many adult weevils in early spring.
- Western robin, *Tardus migratorius propinquus* Ridgway: an important enemy of the weevil in the spring.

Western savannah sparrow, *Passerculus sandwichensis alaudinus* Bonaparte: one of the most important destroyers of weevils; during May, June, and July the weevil forms from one-half to two-thirds of its diet.

Western vesper sparrow, *Pooecetes gramineus confinis* Baird: one-half of its food in June and July is composed of a weevil diet.

In Turkestan the wagtail, *Motacilla* sp., is recorded by Smirnov (1913) as an important natural enemy of the alfalfa weevil in that region. These birds appear in March and destroy great numbers of the larvae.

Domestic fowls, chickens, and turkeys are also effective predators on the alfalfa weevil.

OTHER VERTEBRATES

Among other vertebrates which have been recorded as feeding on the alfalfa weevil by Webster (1912) and Kalmbach (1914) are:

Rocky Mountain toad, *Bufo lentiginosus woodhousei:* devours considerable numbers of hibernating weevils in the spring and other adults in early summer.

Leopard frog, *Rana pipiens:* devours many weevils adjacent to water in low damp fields and along irrigating ditches.

Salamander, *Ambystoma tigrinum.*

Blue racer, *Zamenis constrictor flaviventris.*

Horned toads, *Phrynosoma* spp.

Garter snake, *Eutaenia* sp.

Shrew, *Sorex* sp.

ARTIFICIAL CONTROL

As is the case with many serious insect pests, the alfalfa weevil, even where thoroughly established and widely spread, reacts very differently in its various habitats and does not require continuous artificial control in any. The limitations involved are explained more fully in those portions of this bulletin dealing with climatic range, destructiveness, and natural control. Suffice it to say here that under certain favorable conditions the insect becomes very abundant and destructive. The only justification for going into so much detail concerning the many factors which favor and limit these sudden and devastating appearances is to familiarize the alfalfa producer with all the facts necessary for him to judge the situation in his particular locality with regard to the possibilities of weevil increase and to be prepared to check it before it assumes serious proportions. Concerning the normal conditions with regard to the alfalfa weevil in the Great Basin, Reeves (1927*b*) has made this rather pointed comment:

The most baffling feature of the alfalfa-weevil problem is that, in climates where slightly abnormal weather may prevent weevil damage for a given year, growers

tend to persuade themselves that they will never again find it necessary to control the pest. The result is that the next attack finds them off their guard and a crop of hay is lost. One year of unpreparedness in such a case is more costly than many years of preparation which prove unnecessary. Since weather conditions are uncontrollable, it is safest to assume that the only insurance against damage by weevils is a spray outfit and a supply of calcium arsenate.

FARM PRACTICES

Good farm practices often lend themselves to the control of insect pests. Healthy vigorous crops often succeed in spite of insect attacks. Alfalfa-weevil control is especially successful when correlated with up-to-date farming methods. It involves a number of unusual practices, but any method that adds to the economic success of a crop should fall within this classification. It should not be overlooked that these agricultural practices, as well as artificial control, should be more or less generally adopted by the whole community to be most effective and to insure the greatest good to each individual. Those practices which have contributed to the reduction of the weevil and protection of the alfalfa crop are summarized as follows:

1. Clean Culture.—In view of the fact that the adult weevils spend the winter in such protected places as dead weeds, straw, and refuse of varied kinds, it is apparent that the elimination of such litter, especially in and around the alfalfa fields, will cause the weevils to leave in search of such favorable places or to perish for the want of them. Therefore, the destruction of weeds along ditch banks, fences, roads, and in the fields, and of trash and litter around buildings during the late summer, fall, and winter, will do much to expose the weevils to the killing effects of winter (Parks, 1913).

2. Cultivation.—According to many investigators, particularly Titus (1909*a*), Parks (1913), Reeves, Miles, *et al.* (1916), Harris and Butt (1921), Wakeland (1924), and Snow (1925), cultivation of the alfalfa fields with a spring-tooth harrow, disk harrow, or similar tool stimulates growth, and while it does not actually kill any great number of weevils, aids materially in hastening growth and increasing yield. Spring cultivation before growth starts is especially recommended as a means of warming up the soil, promoting draining and air circulation in the soil, and establishing "a better protective mulch against rapid evaporation" (Wakeland, 1924). Reeves, Miles, *et al.* (1916) advocate going over the field twice. The cost was estimated at from $0.60 to $1.25 per acre, which is more than justified by the increase in yield, if not in the actual reduction of the insect pest. It is also recommended that after the cultivation the ground be smoothed with an ordinary spike-tooth harrow.

Where weevils continue in great numbers, summer cultivation, after the cutting of the first crop, is also recommended in Idaho by Parks (1913).

3. Dragging and Dust Mulching.—One of the earliest methods for destroying the alfalfa weevil in Utah was the use of a homemade brush or wire drag, which was found most effective when used after cultivation. The brush drag, as the name indicates, was made of brush tightly bound and weighted down so as to tear up and pulverize the surface soil, thereby crushing many of the insects, exposing others to the killing heat of the sun, and smothering many in the dust. A wire drag was made by placing several layers of heavy woven-wire fencing under an ordinary spike-tooth harrow with the teeth laid flat and enough weight to pulverize the soil (Reeves, Miles, *et al.*, 1916).

Wakeland (1924) has summarized the value of brush dragging as follows:

> To some extent, brush dragging has been relied on in controlling alfalfa weevil. It possesses some merit as an emergency means of control under certain conditions but is not to be recommended as a practical, dependable method. Reliance on this method is based on the fact that both larvae and adults are easily killed by dust and dry heat. The usual practice is to cut the first crop early and then work up a thorough dust mulch by use of a brush drag or a spike-tooth harrow under which is fastened brush or woven wire. For success in creating a dust mulch the field must be dry at cutting time and until after the hay is hauled from the field. A farmer cannot regulate this factor and a rain may interfere any year with his control plans. Even though it may be possible to keep the field dry, to do so is not good farm practice. Dust mulch often necessitates remarking a field before it can be irrigated. Points for and against dust mulching are:
>
> 1. Under limited conditions it will control weevil on second and third crops.
> 2. It will not prevent loss on first crop.
> 3. It cannot be relied on every year.
> 4. It is costly and slow, and if done properly interferes seriously with farm work and alfalfa growth, for which reasons it cannot be considered a good farm practice.

Snow (1925) has also called attention to the fact that dragging is not effective in rocky fields or for the first crop. Reeves, Miles, *et al.* (1916) object to it because it must be done at the busiest time of the year.

4. Sweeping.—A horse-driven street sweeper was used experimentally after cutting the alfalfa in Utah in 1911 by Webster (1912), but while it killed many of the larvae and pupae in the stubble, the cost was prohibitive.

5. Burning.—An oil burner, such as is used for burning weeds, was tried after cutting. It killed exposed larvae and pupae, but any that were protected from the direct flames escaped (Webster, 1912). Such burners

have been experimented with in California for destroying the pea aphid on alfalfa and gave promising results but at a prohibitive cost.

6. *Irrigating and Silting.*—Irrigation may be classed with cultivating (Hagan, 1918) in its effects upon the alfalfa weevil. It stimulates and hastens growth of the plants, but does not drown many of the various stages of the insect, according to Wakeland (1924). Attention should be called to the fact that after cutting great numbers of the weevils are killed by the heat of the sun, and irrigating prior to cutting would have a tendency to cool the soil and thus nullify much of the killing effect of the heat.

Silting, that is, irrigating in the spring with very muddy water to bury the weevils in a deposit of sediment is suggested for certain limited applicable cases by Reeves, Miles, *et al.* (1916).

7. *Puddling.*—Puddling after irrigation, suggested by Webster (1912) and Reeves, Miles, *et al.* (1916), consists in dragging a leveler, or similar tool, over the flooded alfalfa fields to "mud-up" the weevils. While it is fairly effective, Hagan (1919) believes it to be of doubtful value because of its ill effects upon the physical condition of the soil.

8. *Cutting.*—There is much that might be said concerning the proper time to cut alfalfa for hay to reduce the numbers of the alfalfa weevil. It is well known that exposure to the hot sun destroys many of the larvae and pupae and timely cutting may be employed for this purpose. Whenever the destructiveness of the weevil is such as to check the growth of the alfalfa, especially that of the first crop and when most of the eggs have been laid, which in Utah is about the middle of May (Harris and Butt, 1921), then the crop should be cut and the hay removed as quickly as possible to allow the hot sun to destroy the larvae in the stubble. Snow (1925) refers to this practice as follows:

> Making two cuttings of the first crop, when the alfalfa is 15 or 18 inches high and again two weeks later, has much the same effect as pasturing or killing the eggs and larvae before they do much damage. One cutting, if properly timed to remove the bulk of the eggs and young larvae, may prove equally effective. If this cutting is too late the weevils may be so numerous in the stubble as to prevent the normal growth of the next crop.

Wakeland (1924) cautions against indiscriminate cutting of alfalfa in Idaho. He states:

> Cutting the first crop before it has been seriously injured is practiced in some communities, and occasionally a grower obtains good results. His assumption is that he hauls the eggs and weevils in and thus gets rid of them in his hay. This is not in accordance with facts, and in practicing such a method, knowingly or unknowingly, he is relying on heat and dryness to kill the weevils exposed after removal of early cut hay. Alfalfa cut before the early-blossom stage does not have

the feed value that it has when cut at that time, and persistent early cutting weakens the stand. In a weevil-infested field early cutting is usually accompanied by all the evils described under "Cultural Abuse" [withholding of and wrong application of irrigation water] and many stands have been destroyed almost completely by this practice in southwestern Idaho during the past four years.

Reeves and Hamlin (1931*a*) have summarized the influence of cutting the crop on the alfalfa weevil as follows:

In regions where weevil damage is customary and serious farmers are compelled to time their cutting by the stage of injury instead of the stage of growth; and even where the damage is less regular, and early cutting less necessary, it is practiced to a considerable degree. The purpose is to save the existing crop, but the practice also indirectly reduces weevil damage the following year, and it is probable that by this means the farmers of infested localities, after contending with the weevil for several years, unwittingly lower the weevil population and give foundation to Doctor E. D. Ball's surmise that weevil injury automatically tended to subside within 4 or 5 years after its first appearance.

* * * * * *

However, before parasitism brings about the death of the larvae, the cutting of the first crop produces drastic ecological changes in the alfalfa field, killing almost impartially both parasitized and unparasitized larvae. Within one week after the cutting time in 1930 the larval population declined 96.6 per cent. Only 2.4 per cent of this reduction is accounted for by larvae developing into the cocoon stage, the remaining 94.2 per cent of the decrease being due to heat and starvation. This kill operates on larvae of all stages and conditions, but 91 per cent of the survivors are mature larvae. Some of these spin cocoons during the second week after cutting and others succumb to the adversities of the stubble field, so that, two weeks after cutting, the larval population has almost disappeared. It is then renewed by the hatching of the eggs laid, after the first cutting, by the few surviving overwintering adults.

A survey of present methods of control employed in Utah indicates that cutting at most opportune times, as indicated above, is the most important single factor in keeping the alfalfa weevil in check.

9. Pasturing.—Pasturing with livestock, if judiciously practiced, is another method of reducing the populations of the weevil in the spring of the year. Animals may be turned into the infested fields for a few days, for three or four weeks, or permanently, but Hagan (1919) calls attention to permanent pasturing as an injurious practice. During the egg-laying period and the appearance of the newly hatched larvae, in April and May, sheep, in particular, are effective in destroying great numbers of the eggs and larvae. Reeves, Miles, *et al.* (1916) have advocated that in some cases fields be divided into small enclosures for concentrating the feeding of livestock and more thorough destruction of the weevil section by section. Attention is called to the danger of bloating and the impractibility of pasturing where the alfalfa is needed for hay.

10. Replanting.—Replanting of alfalfa is advocated as a means of maintaining crop production as well as an aid in offsetting losses due to the attacks of the alfalfa weevil. Parks (1913) reports that old stands are injured most by the pest, and Snow (1925) adds that crop rotation may result in increasing the crop of alfalfa and in reducing the numbers of the weevil. Hagan (1919) advocates replanting every four to eight years, but prefers a change every six years, whereas Harris and Butt (1921) recommend planting every seven or eight years.

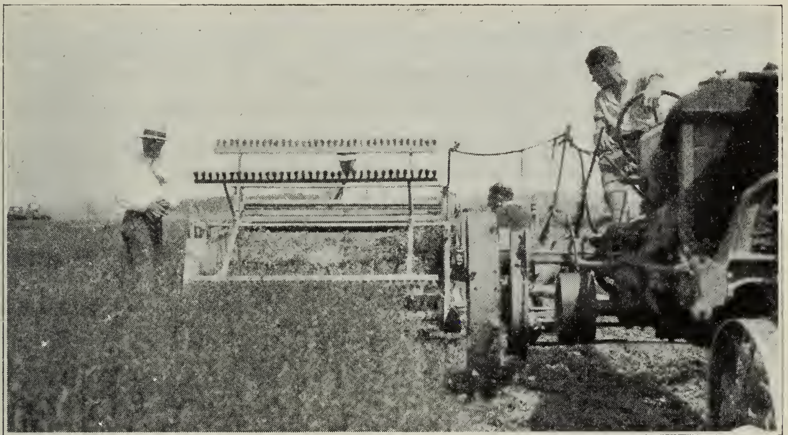

Fig. 16.—A combined mowing and crushing machine in action in an alfalfa field. After passing over the sickle the alfalfa is carried between two powerful rollers which crush the stems and thereby hasten drying in the field.

11. Gathering Machines.—Gathering machines of the ordinary header type, consisting only of the reel and running gear with canvas stretched over the table, at the ends, and across the back to catch the weevils knocked off by the revolving reel, were used by Titus (1910*a*) and a number of farmers in Utah prior to 1910. As many as 145,000,000 specimens of larvae and adults per acre were taken in one field and 166,000 per acre in another. In spite of these large catches the gathering machines did not sufficiently decrease the enormous populations and therefore did not gain favor as a means of economic control.

12. Other Practices.—Among other contrivances which were experimented with in the attempted control of the weevil and which proved ineffective are:

Light traps—the weevils do not fly at night.

Barriers of oil around the fields did not prevent infestations and captured very few adults.

Steaming the stubble after the first crop was removed was unsuccessful.

SPRAYS

Whenever the alfalfa weevil becomes sufficiently abundant to cause serious injury to the alfalfa crop, as has frequently happened in the Great Basin, then the only practical method of handling the situation is the application of poisonous insecticides to effect an immediate check on the ravages of the pest and to save the crop. While the many farm practices previously cited assist in preventing continuous serious attacks, yet they are of little use when once the weevil appears in devasting numbers. It is then that the application of a poison spray or dust will save the alfalfa. While it was generally known to Titus (1910*a*) and others that arsenical sprays would afford an effective means of destroying the larvae of the alfalfa weevil, investigators were cautious in treating growing alfalfa with these materials because of the possible danger to livestock in feeding hay which had been so treated with poisonous compounds. However, during succeeding years trials were made which proved that the small amounts of the insecticides necessary to control the weevil were not seriously toxic to domestic animals, and thus the way was opened to a new solution of the problem of control. These insecticides are applied as sprays and dusts and the relative merits of each type will be discussed separately.

The first satisfactory spray program for the control of the alfalfa weevil appears to have been proposed by Reeves and his associates in 1916 (Reeves, Miles, *et al.*, 1916). Two applications were advocated: one in the spring using 4 pounds of zinc arsenite to every 100 gallons of water and applied at the rate of 50 to 100 gallons per acre; and in places where the weevils reappeared in destructive numbers, a summer application consisting of either 1 pound of paris green to 100 gallons of water or 6 pounds of arsenate of lead paste to 100 gallons of water. All of these combinations were reported satisfactory and paved the way for a great deal of investigational work with arsenicals.

Hagan (1918) called attention to the effectiveness of a spray composed of 5 pounds of paste arsenate of lead to 100 gallons of water but thought it too costly and possibly poisonous to livestock. The next year, however, Hagan (1919) concluded that spraying was as effective and as cheap as cultural methods and recommended arsenate of lead applied at the rate of 2 pounds per acre by means of a sprayer with a 3-nozzle boom attachment to treat a strip 6 feet wide. The application was to be made about 3 weeks before cutting.

In 1920 Reeves and associates (Reeves, Chamberlin, *et al.*, 1920) published complete recommendations for the control of the alfalfa weevil by

spraying. Their findings were based on the results of seven years' experimentation with arsenicals, a summary of which follows:

The best time to spray in the Great Basin (may be different in California) is about 1 or 2 weeks before the first crop of alfalfa is ready for cutting *when the larvae are most numerous.*

Materials and Amounts.—Either arsenate of lead or arsenite of zinc with the addition of a small amount of laundry soap to spread the spray and make it stick to the plants. The formula is as follows:

Arsenate of lead or Arsenite of zinc — powder	2 pounds
or paste	4 pounds
Water	100 gallons
Laundry soap	2 pounds

Application.—Use 100 gallons of the spray mixture per acre at from 75 to 150 pounds pressure.

Equipment.—Power sprayer with sufficient engine power, large tank, strainers, pressure gauges, boom attachment, and nozzles. With proper pressure each nozzle will spray a strip 2 feet wide. A good outfit can carry 10 nozzles and thus treat a strip 20 feet wide. The boom should be about 2 feet above the alfalfa. Each nozzle should deliver 0.9 gallon of spray per minute.

A 10-nozzle outfit is capable of treating at least 25 acres a day.

Cost.—In 1920 the cost of spraying amounted to approximately $1.00 an acre.

Effects of Spray.—The effects of the poison spray should begin to appear in about three days when dead weevil larvae may be found, but the full effects of the treatment cannot be expected until the fifth day and after.

In Oregon, Fulton (1921) recommended a spray of 2 pounds of powdered arsenate of lead and 100 gallons of water to which a little soap is added, applied at the rate of 100 gallons or less per acre one or two weeks before the first crop is cut or when the larvae are numerous enough to affect the crop seriously.

In Colorado arsenate of lead and arsenite of zinc, as recommended by Reeves, were suggested by List and Wakeland (1919), but little control work has been necessary in that state.

Calcium Arsenate.—In Nevada in 1925 calcium arsenate was recommended (Snow, 1925) at the rate of from 3 to 4 pounds per 100 gallons of water applied to from 1½ to 2 acres of alfalfa at a pressure of from 150 to 220 pounds. When applied with horse-drawn traction sprayers, from 20 to 30 acres a day were treated at a cost of $0.68 an acre. One

application made during the period from May 26 to June 13 was usually sufficient, but in rare cases a second spray was applied two weeks after the first.

DUSTS

During recent years dusting has practically replaced spraying in the control of the alfalfa weevil. This is in great part due, not to the greater efficacy of dusts, but rather to the ease and rapidity of application, which make them also less expensive. Then too they may often be applied with hand or light traction equipment when heavy spray outfits could not be dragged over the wet fields.

Dusting with a mixture of sulfur and calcium arsenate showed promise in Utah and Idaho and the results obtained by Reeves and Wakeland are given by Newton (1922). Snow (1925) conducted extensive experiments in Nevada with dusts and recommended a traction duster equipped with a thin-iron, hollow, 18-foot boom, 4 inches in diameter at the center, tapering gradually to ¾ of an inch at each end, connected to the blower at the middle with a 4-inch T-shaped tube, and supported by a 4 × 4 inch timber, 19 feet long. In a row, on the underside of the boom, are 3/16-inch holes, 1½ inches apart, through which the dust is blown out to cover a strip the width of the boom. Applications with such a machine are effective and should be made when the weather is calm. Dew on the alfalfa helps to stick the powder to the plants. In general best results were obtained from a mixture of equal parts of calcium arsenate and dusting sulfur.

Hand dusters and aeroplanes were later used with encouraging results as reported by Howard (1926). Reeves (1927*b*) adds this caution:

> The use of calcium arsenate in the form of dry dust offers many mechanical advantages, such as getting rid of the great weight of water used in spraying. The dust is applied by means of a traction-driven fan or blower or by airplane, and the mechanical problems involved have been satisfactorily solved. The effect upon the crop has been in some cases even better than that of spraying but until greater uniformity of results is obtained it cannot be recommended.

Doten (1928) stated that dusting with calcium arsenate was as effective as spraying in Nevada in 1927. He further called attention to the fact that it was simpler, required less power, and eliminated the heavy hauling of water. Specially constructed horse-drawn geared dusters were the most promising. Schweiss (1932) also showed clearly that in Nevada, dusting with arsenicals was more effective and cheaper than spraying. Sorenson (1932) confirmed the work of Reeves, Wakeland, Snow, and others concerning the effectiveness of a dusting mixture composed of equal parts of calcium arsenate and sulfur for the control of the alfalfa

weevil in Utah. It was applied at the rate of 5 pounds (2½ pounds of calcium arsenate) per acre at a cost of approximately $0.52 an acre. On the second day after application 50 per cent of the larvae were dead, and 90 per cent within a week.

In middle California in those fields where alfalfa has received the best care none of the infestations of the alfalfa weevil have been sufficiently serious to warrant control measures. Rather serious damage has been noted in poorly kept fields. In case artificial control is necessary in the future, experiments will be immediately undertaken to determine the most effective and least expensive method.

EFFECTS OF THE POISON SPRAYS AND DUSTS UPON THE ALFALFA WEEVIL

All investigators of the alfalfa weevil appear to agree that sprays and dusts are specially valuable in killing the larvae and in this type of control work this point must not be overlooked. The larvae begin to die on the second and third day after treatment, but the full effects of the poisons are not apparent for about a week. The effects of the poisons on the adult weevils are not so well known, but Snow (1925) states:

> The adult weevils after feeding for a few days upon the sprayed alfalfa become sick and stop feeding for a few days and then recover and return to the tops of the plants, by which time the effects of the poison have worn off and the plants have put out new growth. This conclusion is supported by laboratory experiments in which adults have been fed sprayed alfalfa and by field observations which have shown that they are sluggish and act sick for a few days after field has been sprayed.

EFFECTS OF POISON INSECTICIDES APPLIED TO ALFALFA ON LIVESTOCK

In all cases where it becomes necessary to apply arsenical dusts and sprays to alfalfa for the control of the alfalfa weevil, the first question that naturally arises in the minds of the grower is, "What effect will such poisons have upon livestock consuming the treated alfalfa?" That this same inquiry was uppermost in the minds of the entomologists is shown by the fact that early in the alfalfa-weevil investigations, poison sprays, which were at once recognized as effective destroyers of the weevils, were not recommended until after extensive feeding experiments with livestock were conducted to test the effects of the spray on the animals. List and Wakeland (1919) were among the first to state that the arsenate of lead and zinc arsenite sprays were not harmful to livestock. Reeves, Chamberlin, *et al.* (1920) followed with the statement:

There have been many inquiries as to the danger of poisoning livestock by feeding sprayed hay, which are all answered by the fact that such hay is shown by analyses and feeding tests to contain too little poison of any kind to injure farm animals. Many of the cattle which are fed upon it probably take in more arsenic with their drinking water than with their hay, and as for the lead content, few of them would under any circumstances live long enough to show the least effect of it.

In Nevada, Snow (1925), discussing poison insecticides applied to growing alfalfa for the control of the alfalfa weevil, states: "Such poison never injures the hay as feed. At cutting time too little poison remains to make the hay dangerous."

Wakeland (1925) concludes: "Chemical and feeding tests indicate that there is no danger of injury to livestock from eating sprayed hay where the recommended quantity per acre is used. Many reports have been circulated to the contrary, but dozens of cases investigated have shown these reports to be without foundation."

A case is also cited by Wakeland (1925) where "A dairy herd was fed freshly cut, sprayed, immature first-crop alfalfa hauled from the field before it was entirely cured. Part of the slipload was rained on and fed wet. The following day a load of wet hay was hauled and the cattle fed on it for two days. The entire herd went off feed, became badly purged and dropped heavily in milk production." An investigation conducted by the State Veterinarian of Idaho showed "severe gastral enteritis due to sudden change of food from very dry, coarse cutting of 1928 hay to immature, uncured, wet hay and aggravated to a very minor degree by calcium arsenate that had been recently applied as a spray." He continues:

Analysis of the hay made by the Station Chemist showed it contained 43 parts of As_2O_3 (metallic arsenic) per million. Thus, a cow eating 30 pounds of hay per day would consume 9.03 grains of metallic arsenic daily. Hay containing twice this amount has been fed by the Idaho Experiment Station with results that were entirely satisfactory. Testimony of Dr. H. C. Gardiner [Reeves, 1925], in the Riverside Dairy Case in the U. S. District Court of Utah, is to the effect that an animal the size of a cow can eat in safety 30 grains of arsenic daily and that the fatal dose is 300 grains.

* * * * * *

The preponderance of evidence is that there is no danger to livestock from eating sprayed hay. . . . In all future recommendations concerning spraying for alfalfa weevil the Experiment Station will take the precaution to advise thorough curing of hay before feeding and to avoid feeding hay while wet or in a soggy moldy condition and will advise against abrupt changes from non-nitrogenous foods to alfalfa. [Wakeland, 1925.]

Reeves (1927*b*) adds the following:

The arsenic content of sprayed hay ranges from less than 1 grain in terms of white arsenic to nearly 29 grains for 30 pounds of hay, and is usually between 5

and 10 grains. The exceptionally large quantity of 29 grains in one day's ration is within the limit of tolerance of horses and cattle [Reeves, 1925]. It is, therefore, entirely safe to feed sprayed hay to livestock, and there need be no case of arsenical poisoning unless white arsenic, sodium arsenite, or some equally virulent poison is substituted, through carelessness or ignorance, for calcium arsenate. It is important, however, for the man who sprays alfalfa with any arsenical compound to know the symptoms of arsenical poisoning, so that he can distinguish between that malady and colic, overeating, and starvation, the two former of which it is popularly but mistakenly supposed to resemble, and the latter of which is actually much like it.

Arsenical poisoning is produced only by a large dose of arsenic which is absorbed from the intestines into the circulation and attacks the liver. In severe arsenical poisoning there occurs an overintoxication resulting in an actual destruction and conversion into microscopic fat of the cells of liver tissue proper within their framework of connective tissue; and the liver loses its ability to eliminate poisons. In case of a dose sufficient to cause poisoning there is always a considerable quantity of arsenic found in the liver; that is, from 10 to 15 times as much as in the other tissues of the body.

Arsenic produces no lesion of the bones, such as rickets; its effect upon the nutrition of the body, when given in medical doses, is of an opposite character. If an animal is anemic and the nutrition is faulty, arsenic is administered and seems to have the power of taking the place of iron in the red blood corpuscles.

Arsenic does not affect the lungs or trachea except as a tonic, and there is no shortness of breath except as a consequence of pain and shock to the nervous system in acute cases or of stiffness in front of the ensiform cartilage in chronic poisoning.

Another important contribution is by Frederick (1930), who reported the results of a rather extensive feeding experiment as follows: "Alfalfa dusted with calcium arsenate, applied at the rate of 2 pounds to the acre and subsequently cured for hay was fed to livestock throughout a feeding season of from 4 to 6 months without injury to cattle, sheep, and horses."

A recent case of arsenical poisoning to livestock in Germany, in connection with the control of the alfalfa weevil, is cited by Krüger (1933): "Cases of poisoning of pastured cattle by arsenical insecticides have occurred in Germany. In an instance here recorded 3 cows were killed in mid-September by feeding on bird's foot trefoil (*Lotus corniculatus*) that had been dusted on June 18 with an arsenical preparation against *Phytonomus variabilis* (Hbst.). The seed crop had been harvested in August."

In this case no data are given concerning the amount and concentration of poison dust applied.

SUMMARY

The alfalfa weevil, *Phytonomus variabilis* (Herbst), is an Old World insect which occurs more or less coextensively with alfalfa culture throughout Europe, northern Africa, and Asia. It was introduced into the Great Basin of the United States at the beginning of the Twentieth Century and was first noted as a pest of alfalfa in Utah in 1904.

Since its initial introduction into Utah the weevil has spread into the states of Wyoming, Colorado, Idaho, Nevada, Oregon, and California.

In California the insect first appeared east of the Sierra Nevada in Sierra County in 1923. Gradually its distribution extended into Plumas, Lassen, Alpine, and Mono counties. By unknown agencies it was carried into the middle part of the state, being discovered in San Joaquin County in 1932. It now also occurs in Alameda, Contra Costa, Merced, Santa Clara, and Stanislaus counties.

The adult weevils are about 3/16 inch long and of a gray-brown color. They hibernate in the fields during the winter and the females deposit their minute, shining, oval, yellowish-orange eggs in the stems of the alfalfa plants. The larvae are legless, pale-green worms with white dorsal stripe, and 1/4 inch in length when full grown. They feed on the leaves and stems of the host plants and spin globular, lace-like cocoons at the bases of the plants in which transformation to the adult or weevil stage occurs.

The climatic conditions of California more nearly simulate those of the Mediterranean region than those of the Great Basin. However, the summer temperatures in the interior valleys of California are much higher than in southern Europe. While there is much more similarity in amount of rainfall in the two regions, California has much dryer summers and this condition coupled with the higher temperatures may have a marked effect on reducing the destructiveness of the weevil in the warmer interior valleys and the semiarid alfalfa districts of the southern part of the state.

The most important food plant of the alfalfa weevil is alfalfa. Certain other members of the genus *Medicago,* including bur clover and several of the genus *Melilotus,* particularly the yellow sweet clover or melilot, are of lesser importance, and a few of the true clovers and vetches are suitable hosts under certain conditions. Of the wild plants in California bur clover and yellow melilot are the most important in maintaining the insect outside of alfalfa fields.

In parts of Asia, Europe, and the Great Basin in the United States severe damage to alfalfa has frequently occurred. In the Great Basin the

most serious injury is done to the first crop. In middle California the only damage of importance has occurred in alfalfa fields that were poorly cared for or completely neglected.

The alfalfa weevil spreads naturally by crawling and by flight, but it may also be carried by wind and by water in irrigating ditches and canals. Artificially it may be transported long distances in hay, railroad cars, automobiles, and similar agencies of commerce.

There are many natural enemies which prey upon the alfalfa weevil. Birds are already a factor of considerable importance wherever the insect has become established over a period of time. Among the insect enemies the most important are the tiny hymenopterous parasites which attack the eggs, larvae, and pupae of the pest. Several of these parasites have recently been introduced into California from the Great Basin and from southern Europe.

Many methods for artificially controlling the alfalfa weevil are employed in the Great Basin of the United States. Among the most important farm practices are cultivating or disking the fields, pasturing, and the proper timing of the cuttings. The last is by far the most valuable method for reducing weevil populations and is the only one now used in many districts. The application of poisons as sprays and dusts has also proved effective. A spray composed of 2 pounds of powdered arsenate of lead or arsenite of zinc, 2 pounds of laundry soap, and 100 gallons of water, has been used with great success; the quantities given are sufficient for 1 acre. A dust prepared by mixing together equal parts of powdered calcium arsenate and dusting sulfur and applied at the rate of 5 pounds per acre has been used successfully in Nevada and elsewhere.

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